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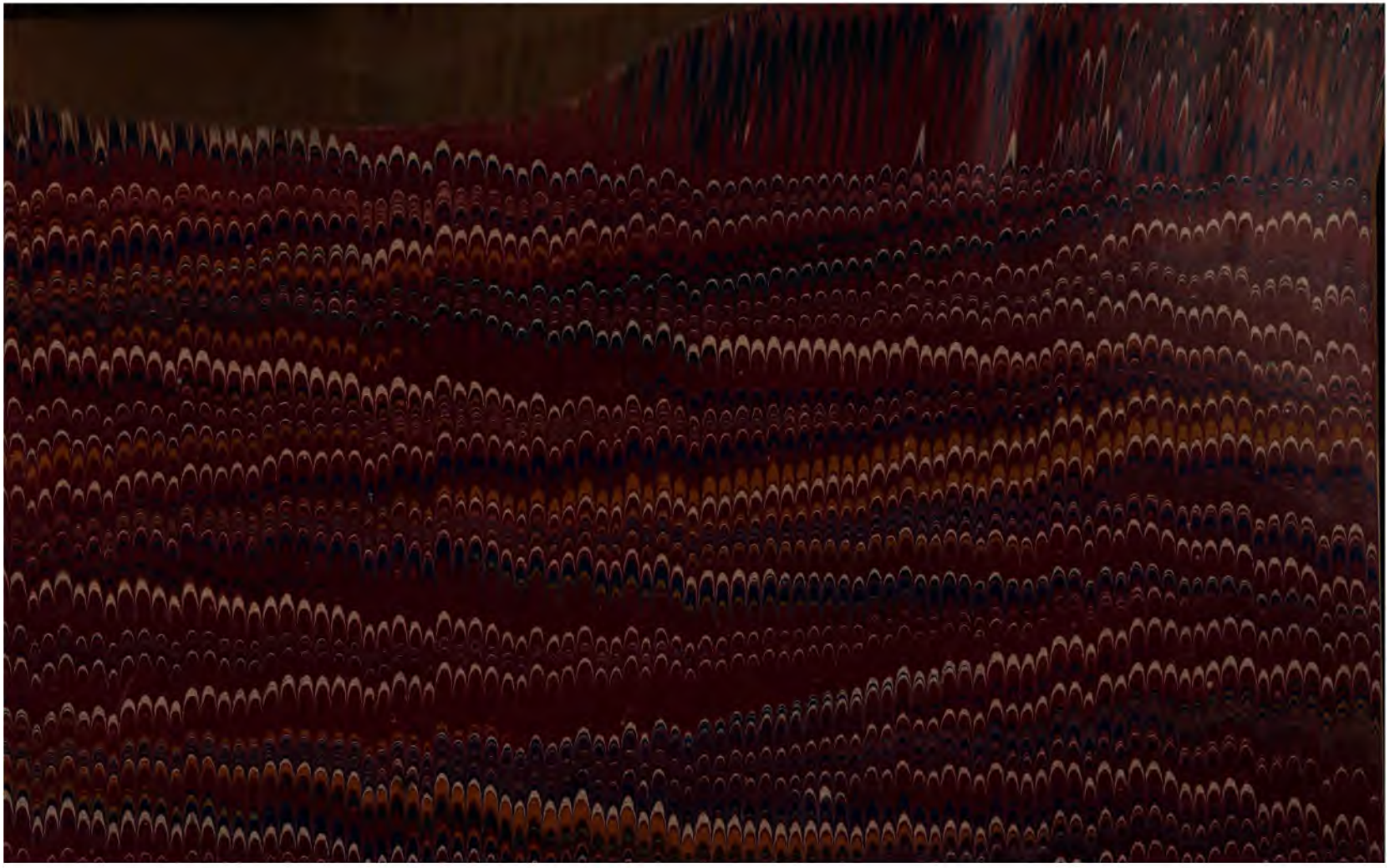

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51ST CONGRESS, 1st Session. | SENATE. | REPORT 928, Part 5.

REPORT

OF THE

SPECIAL COMMITTEE

OF THE

UNITED STATES SENATE

ON THE

IRRIGATION AND RECLAMATION OF ARID LANDS.

VOL. IV.—STATEMENTS BY DIRECTOR POWELL AND OTHER OFFICERS OF THE U. S. GEOLOGICAL SURVEY.
CONSULAR REPORTS.
GENERAL REPORT ON IRRIGATION IN UNITED STATES.
MISCELLANEOUS PAPERS.

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VOL. IV.

STATEMENTS BY DIRECTOR POWELL AND OTHER OFFICERS OF THE U. S. GEOLOGICAL SURVEY.

REPORTS OF UNITED STATES CONSULS IN COUNTRIES USING IRRIGATION.

MISCELLANEOUS PAPERS ON SUBJECT OF RECLAMATION.

HINTON'S REPORT ON "IRRIGATION IN THE UNITED STATES." RE-EDITED BY ORDER OF THE COMMITTEE.

WASHINGTON DIVISION.

WASHINGTON, D. C., *January* 17, 1890.

The committee met pursuant to the call of the chairman.

Present, Mr. Stewart (chairman), Mr. Plumb, Mr. Casey, Mr. Moody, Mr. Reagan, and Mr. Jones of Arkansas.

STATEMENT OF J. W. POWELL, DIRECTOR OF THE GEOLOGICAL SURVEY.

Director POWELL. Mr. Chairman and gentlemen of the committee, since the return of the committee from the West, having ascertained special questions in which the members of the committee were interested, I have devoted almost all my time to the collection of the data which they seemed to require, and to assembling those data in such manner as to present to the committee a body of material that should as far as possible be a repository of facts in relation to arid lands. For this purpose I have not only devoted most of my own time but have employed from five to twenty-five men in the office of the Geological Survey getting together the facts.

I now present before the committe a map of the arid region exhibiting the distribution of the land already irrigated. The committee will see on this map a red line along the eastern border.

The CHAIRMAN. How is that map entitled?

Director POWELL. It is entitled, "Map showing the irrigated areas of the United States."

Senator PLUMB. That corresponds to the line drawn on other public maps, I suppose; for instance, the one at the White House, separating the arid from the subarid regions?

Director POWELL. That map at the White House I made some fifteen years ago. I have more complete data now.

Senator PLUMB. Do the lines run to the same places?

Director POWELL. Not quite.

Senator CASEY. Is that line drawn at about the one hundredth meridian?

Director POWELL. It is very near to it, but not exactly at the one hundredth meridian. There is a border zone along the eastern side of

the line—a doubtful region—the region in which at some times rain falls in quantities sufficient for agriculture and at other times in quantities not sufficient for that purpose. The line itself is drawn conservatively, so as to include only those areas now generally, perhaps universally, recognized as being arid to such an extent as to require irrigation from year to year.

The greatest change I have made since the old maps were constructed is in the western border. We are able to trace out more accurately the lines on the western border where irrigation is necessary. I have also left out the northern portion of the valley of California in which irrigation is not absolutely necessary.

The CHAIRMAN. In the northern Sacramento Valley?

Director POWELL. Yes.

The CHAIRMAN. Irrigation districts are being rapidly organized there.

Director POWELL. Yes, but I have only indicated here the area where irrigation is absolutely necessary. The total area of the regions thus embraced within the two lines is about 1,340,000 square miles. If we include the subhumid zones on either side, where irrigation must be practiced some years to secure crops, the total area will be about one-half of the United States exclusive of Alaska.

A glance at the map will exhibit the districts of country where irrigation is now in progress. From the data we have collected we find that about 8,000,000 acres of land have been irrigated and are under cultivation, and that a little more than 10,000,000 acres of land are under ditch. I have that all plotted on the map, except some few places yet to be completed—little outlying districts where 10, 20, or 30 acres are irrigated by little springs, etc.—a few in Nevada, Idaho, and Oregon, and some in Wyoming. They will very soon be completed.

I here present a table by States, setting this forth:

IRRIGATED AREAS—TOTALS.

States and Territories.	Under ditches constructed or projected.	Irrigated and under ditch.	Percentage irrigated to total area of State.	Authority.
	Acres.	*Acres.*		
Arizona	455,600	175,000	0.2	T. E. Farish.
California	6,000,000	3,000,000	3.0	R. J. Hinton.*
Colorado	----------	2,250,000	3.0	Do.
Idaho	740,000	400,000	0.7	J. C. Straughn.
Montana	----------	†348,000	0.3	R. S. Tarr.
Nevada	----------	75,000	0.1	R. J. Hinton.*
New Mexico	1,350,000	638,000	0.8	T. B. Mills.
Oregon	191,000	119,000	0.2	W. G. Steel.
Utah	----------	802,000	1.5	F. H. Newell.
Wyoming	1,227,819	†500,000	0.8	E. Mead.
Total	----------	8,307,000	----------	

*Mr. Hinton's estimates are based on various reports and figures, the details of which are not now accessible.

†Including large areas of hay lands in Wyoming, probably 90 per cent. meadow.

The figures above are not comparable among themselves, as they are derived from many sources and made by various persons, each having different purposes and ideas as to what constitutes irrigation.

NOTE.—Mr. Hinton's figures are those of his report on "Irrigation in the United States" made in 1885-'86 and published in 1887 by order of the United States Senate.

ARIZONA.

The estimates for Arizona are based on the report of Mr. T. E. Farish, Commissioner of Immigration, bearing date May 25, 1889. Following is a summary of his figures:

County.	Reclaimable.	Under ditch.	Cultivated.	(Newell) estimated under irrigation.
	Acres.	*Acres.*	*Acres.*	*Acres.*
Mohave	.....	.....	1,000	1,000
Yavapai	.....	.....	11,680	10,000
Apache	.....	.....	9,000	9,000
Graham	.....	47,000	.....	10,000
Gila	.....	.....	6,600	5,000
Pinal	.....	71,600	12,000	10,000
Maricopa	1,250,000	300,000	132,800	100,000
Yuma	.....	30,000	5,000	5,000
Pima	300,000	7,000	5,000	5,000
Cochise	100,000	.....	20,000	20,000
Total	1,650,000	455,600	203,080	175,000

COLORADO.—PARTIAL STATEMENT.

District.	Under ditch	Irrigated.	District.	Under ditch	Irrigated.
	Acres.	*Acres.*		*Acres.*	*Acres.*
1, State engineer's report, 1888	150,000	39,720	15	2,771	4,544
2, State engineer's report, 1888	.....	46,150	16	32,623	12,713
3	.....	108,900	20	396,360	100,610
4	.....	69,910	21	57,920	45,183
5	.....	86,655	22	46,211	33,855
6	.....	50,000	41 and 60, Montrose County	.....	*5,000
7	98,558	68,905	40. Delta County	.....	*2,000
8	.....	3,000	42 and 63. Mesa County	.....	10,390
9	6,915	3,740	43. Garfield County	.....	1,000
14	13,694	7,264	Total	.....	699,539

* Assessor.

The above comprises all the figures, official or otherwise, that are at present in this office. It is evident, on inspection, that these estimates are very incomplete, far below the actual irrigated acreage even in the districts given, while many districts are not mentioned.

IDAHO.

[From the report of the governor, 1889.]

Counties.	Approximate area.	Irrigated and in process as reported.	Irrigable as reported.	The irrigable land now irrigated.	Total area reclaimable.
	Sq. miles.	*Acres.*	*Acres.*	*Per cent.*	*Per cent.*
Ada	2,424	60,000	900,000	6.25	62
Alturas*	2,100	14,500	268,000	5.13	21
Bear Lake	†1,300	21,500	40,000	35.5	74
Bingham‡	12,364	284,750	2,503,500	10.5	35.5
Boisé	3,024	83,500	262,000	24	18
Cassia	5,100	82,000	655,000	11.1	22.5
Custer	4,350	24,000	446,000	5.1	17
Elmore	2,700	10,000	230,000	4.2	14
Lemhi	4,300	10,000	600,000	1.64	22.2
Logan	5,200	50,000	1,250,000	2.6	39
Oneida	2,600	38,800	148,000	20.8	11.2
Owyhee	7,812	21,300	248,500	8	42
Washington	2,900	40,000	500,000	7.4	29
Total	56,174	§740,350	8,051,000	9.2	24

* Much on Lost River and lava bed. † This area includes the lake. ‡ Much of this is "in process."
§ The land actually under ditch at present can not be much over one-half of this amount—evident from the amount of water known to be used in certain counties. Estimated 400,000 acres now under ditch.

MONTANA.

[From assessor's returns.*]

County.	Cultivated.	County.	Cultivated.
	Acres.		*Acres.*
Deer Lodge	49,875	Fergus	12,696
Gallatin	47,330	Cascade	9,020
Madison	44,204	Yellowstone	7,357
Jefferson	37,000	Park	6,759
Meagher	32,300	Silver Bow	4,461
Lewis and Clarke	25,968	Dawson	109
Custer	21,812	Choteau	14,378
Beaver Head	20,971		
Missoula	13,862	Total	348,102

*As the statements upon which this table is based were made by an assessor, and were to form the basis of taxation, it is probable that they are considerably under-estimated. I think that it is safe to say that in 1888 there were 500,000 acres of land under cultivation, and the amount is probably not much greater the present year. (Report of R. S. Tarr, June 21, 1889.)

It should be noted that this estimate is based on the assessor's returns of all lands under cultivation.

The largest item of this is 209,000 acres of meadow.

Total acreage of crops (nearly all irrigated)	348,000
Total acreage of meadow	209,000
	139,000

This gives 139,000 acres of small grains and vegetables. This latter figure should be taken in comparison with other States and Territories, since in these latter meadow or grazing lands form but a small item.

NEW MEXICO.

[Estimate of land and ditches by T. B. Mills, June 24, 1889.]

County.	Under ditch.	County.	Under ditch.
	Acres.		*Acres.*
Bernalillo	12,421	Santa Fé	9,820
Colfax	133,400	Sierra	8,673
Doña Ana	37,621	San Juan	20,000
Grant	8,721	Socorro	73,464
Lincoln	100,000	Taos	88,763
Mora	51,279	Valencia	26,429
Rio Arriba	29,623		
San Miguel	38,241	Total	638,455

Projected ditches and ditches under construction will serve in addition, 722,000 acres.

OREGON.

[Report of W. G. Steel, June 27, 1889.]

County.	Irrigated.	Irrigable under ditches.	County.	Irrigated.	Irrigable under ditches.
	Acres.	*Acres.*		*Acres.*	*Acres.*
Baker	5,000	10,000	Lake	5,000	5,000
Crook	8,000	8,000	Malheur	40,000	60,000
Gilliam	3,000	5,000	Morrow	6,000	18,500
Grant	10,000	10,000	Umatilla	5,000	7,000
Harney	20,000	20,000	Union	5,000	8,000
Klamath	5,000	30,000	Wallowa	7,000	10,000
			Total	119,000	191,500

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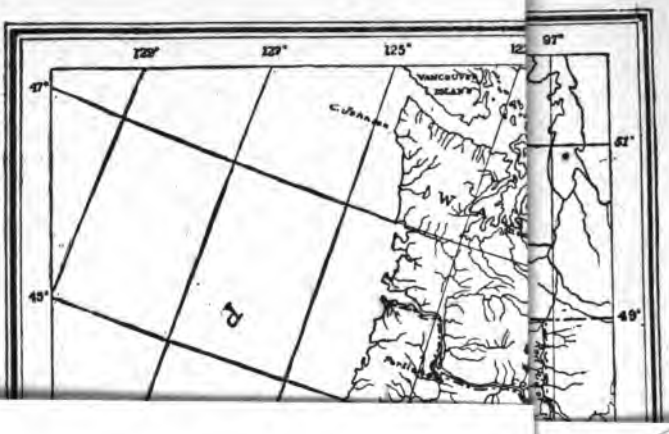

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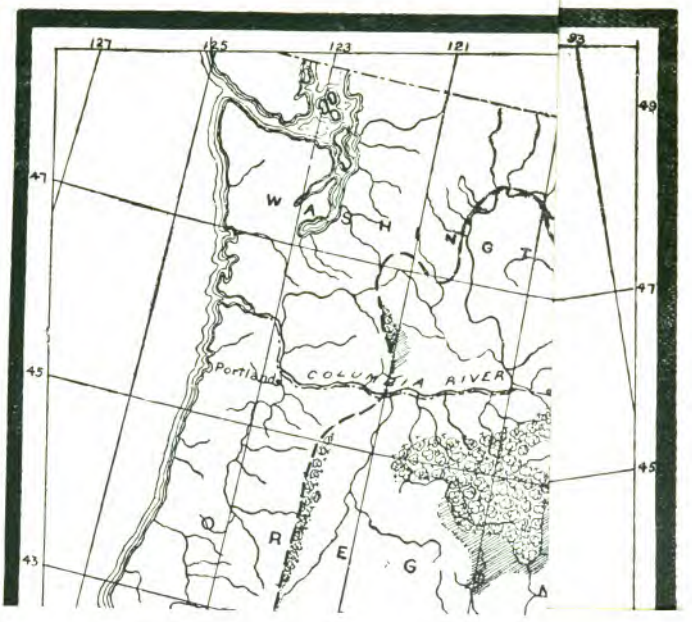

UTAH.*

County.	Land under irrigation.	1889 actually irrigated.	Dry farming.	Arable land not irrigated.
	Acres.	*Acres.*	*Acres.*	*Acres.*
Beaver	14,670	7,450	4	48,080
Box Elder	88,695	11,740	24,090	159,046
Cache	89,025	53,489	18,653	68,917
Emery	44,140	22,406	.....	298,680
Iron	9,107	6,937	100	56,200
Garfield	13,365	7,635	.....	33,046
Juab	9,000	5,300	400	33,000
Kane (county survey)	1,625	.....	.....	1,750
Millard	104,428	11,150	450	488,773
Morgan	8,804	6,687	624	2,823
Pi Ute	29,080	15,285	.....	22,260
Rich (county court)	40,811	.....	.....	44,749
Salt Lake (partial)	44,489	22,982	6,875	89,027
San Juan	770	500	.....	750,000
San Pete	45,506	24,014	1,350	68,605
Sevier	32,874	24,914	.....	30,150
Summit	24,115	20,825	800	14,950
Tooele	6,122	4,080	1,340	120,342
Uintah	33,750	18,818	.....	12,810
Utah	96,097	60,520	6,910	112,680
Wasatch	21,500	15,200	10	21,000
Washington	7,435	6,235	10	22,250
Weber	37,048	25,270	4,465	26,265
Total (except Davis County)	802,456	371,437	66,191	2,525,403

* Statistics derived from Mormon Church records.

WYOMING.

[From Meade's letter of May 9, 1889.]

Statement.—November 1, 1888, amount of land under ditch, 1,227,819 acres (1,918 square miles). "Probably below the truth."

Actually irrigated (including hay lands), 500,000 acres; (agricultural, 50,000acres). Duty, 1 section foot to 80 acres.

Director POWELL (continuing). Do the Senators wish to ask any questions in relation to any special districts? I thought I could assemble on a map a large amount of information and save much oral description. I have had this map engraved. The plates on copper are now in the Geological Survey, and, if desired by the committee, the maps which I present can be incorporated in their report, so that the whole matter may be presented in one body. (See map.)

I have also prepared a map entitled "A map showing the wooded area of the arid region," in which I have delineated in two colors all the forest areas of the region, and it is done with some minuteness and care. The dark green represents all the areas the forests of which are valuable for timber for commercial purposes. Those forests are composed of pines, spruces, hemlocks, firs, and sequoias. (See map.)

The area covered by forests in this manner in that region is less than one-tenth of the arid region, that is to say, one-tenth is covered with forests of commercial value. It must be understood that these forests are all at a great elevation. They are all on the mountains or very high plateaus. The forests grow invariably in regions either where agriculture is impossible or where agriculture pays but very poorly. They are in regions where snow accumulates through many months of the winter, and where frosts may be expected in almost any month of the summer. For that reason the regions where merchantable and valuable timber grows, such as I have been speaking of, have not lands that are susceptible of practical agriculture. They will grow some grains, it may be, and some potatoes, some rye, and a few other things, but in the main, agriculture is impossible there, and the crops which can be cultivated are few. The growth would compare with that of Norway and of southern Alaska.

The CHAIRMAN. What is the altitude?

Director POWELL. It varies. In the north the lower margin is about 5,000 feet, and that margin rises southward to about 7,500 feet, while the upper margin is about 9,000 feet at the north and about 11,000 feet at the south. It is about at that elevation that the timber is found. This timber, in the main, however, is scant. There are some places where the forests are dense. Usually, the pine and fir and sequoia forests are open. The trees are scattered and the forests are interspersed with glades and prairies in such manner that all the timber could grow advantageously on one-fourth of the area they now occupy, and still the ground would not be crowded—the trees would be scant.

Not only are those forests interspersed with prairies and with naked glades and "parks," as they are very often called in that country, but the forest area being, in the main, mountainous area, there are many cliffs, crags, and mountain sides of naked rocks which are not covered with timber. So that on the map an amount of forest area appears much larger than it actually is. On this scale it is impossible to exclude these small tracts which are treeless.

In addition to the forests of commercial value, forests composed in the main of piñons or nut-pines, of cedars, and of small oaks are found in California. These trees are valueless for ordinary commercial purposes. That is, they can not be cut into timber; they are too small for that purpose; but they have great value for fire-wood, fencing, and many domestic purposes. These lie much below the pine forests. These piñon and cedar forests are on the low plateaus and on the rocky hills. In addition to those along some of the streams, as on the Upper Missouri, the Yellowstone, and other streams, down on the bottoms are found forests of cottonwood. Of these all that are worth mentioning are delineated on the map.

The area covered with forests of this class, where the trees are valuable only for fire-wood and other domestic purposes, is slightly greater than the other. A little over one-tenth of the area is covered with forests of this character. Some of the lands covered with this description of forest are valuable for agricultural purposes, but not all. Some are high, others are on rocky hills, and in situations where they can not be used for agriculture.

I wish to incorporate the following table showing by States and Territories the area and character of these forests.

Approximate area in square miles of timbered lands in the arid region.

State.	Fire-wood.	Merchantable timber.
	Sq. miles.	*Sq. miles.*
Washington	1,050	1,080
Idaho	8,600	9,800
Montana	6,500	21,000
Oregon	3,500	8,700
Wyoming	7,300	15,700
South Dakota	2,400	400
North Dakota (river bottoms)	200	.....
California	20,300	11,000
Nevada	5,400	700
Arizona	26,510	11,700
New Mexico	21,540	14,490
Colorado	15,000	23,500
Utah	14,000	7,700
Total	132,300	125,270
		132,300
		258,270
Total area of arid region, square miles		1,335,126

Senator REAGAN. Did you extend your information down to the Texas territory?

Director POWELL. I have not hitherto done so. I have only a small portion of the information, such as I gathered this summer, but I have been for twenty years gathering these data in the other regions.

I wish now to say a word or two with regard to the preservation of forests.

The forests are destroyed frequently by fire. The amount of timber used by man is comparatively inconsiderable. I witnessed one fire twenty years ago in Colorado which destroyed more timber than the people of Colorado have used since the settlement of that country, and I have myself witnessed five or six fires in Colorado of equal magnitude. I have witnessed elsewhere in the mountains very great fires. They are well known. As some of you will remember, during the journey of the committee this past season we passed through the mountainous region of Montana, eastern Washington, eastern Oregon, Idaho, and down into Utah before a mountain was seen, because the whole country was enveloped in smoke as in a dense fog.

These fires are exceedingly destructive. I have with me a map of Utah which will show how destructive they are. This map was made twelve or fifteen years ago and shows simply the areas which were destroyed by fire at that time. I will present it to you for a moment so that you may see how it looks. (See map.)

The blue represents the standing timber at that time—twelve years ago. The brown represents the burned timber at that time. I have no doubt that if a map were made to-day of that same region it would show that much of that blue area has been destroyed in twelve years. The green exhibits the irrigable areas as determined at that time. The forests are chiefly coniferous and needle-bearing, and are charged highly with resin, and so exceedingly inflammable; and for this reason fires are greatly destructive. Then, since the white man has come into the country, the forests have not been annually burned. In old times, when the Indians occupied that country, they systematically burned the forests every fall. By so doing they unconsciously, though not for that purpose perhaps, prevented the total destruction of those forests.

If a forest of coniferous trees is protected from fire for a series of years until the ground is covered with an accumulation of cones, needles, twigs, and brush, then the fires have something on which they may feed. If then, by accident or design, a fire is kindled in such a forest it sweeps through and destroys it. So the forests are being destroyed not for want of protection, but because they are protected from fires. The only proper preservation of those forests consists in a systematic annual burning. If this burning is accomplished at a season of the year when the ground is not too dry the whole accumulation on the surface of the ground may be burned up and destroyed and the trees remain.

Senator JONES. Do you think it would now be practicable (with the accumulation of underbrush that years have produced) to burn any of those forests without destroying the timber?

Director POWELL. Yes; if burned in seasons of dampness, when the forests are not too dry. Fires are destructive in seasons of great dryness or aridity.

Senator JONES. Then, in the districts where the forests have been destroyed by fire, the annual burnings would have to be dispensed with until the young trees got sufficiently large to be safe from destruction by fire?

Director POWELL. If the burning were done at a dry time the smaller trees would be burned; but if the fires were set at a comparatively wet and moist time, and systematically, and if small areas were burned, and burned out, and started again when not too dry, they could be burned without destroying the small trees. In this matter I have had some experience, for I was a farmer's boy in a prairie region and have taken part in such matters. I have burned forests for their protection many times in my life.

The arid region, as I have shown, has already been developed to a great extent for agricultural purposes. In that region there are mines of gold, silver, lead, iron, coal, and so forth, so that a great deal of the country is being settled and in some places it is comparatively densely settled, so that population is now distributed in every valley of importance throughout the region.

In the progress of irrigation and development of that country by which 10,000,000 acres of land have been put under canals, and provision made for the irrigation of that quantity, a large experience has accrued, so that the problems involved—scientific, industrial, and political—have been pretty well developed.

I now show you a map of the arid region exhibiting the areas underlaid by coal, so far as the coal of that country has been determined.

You will observe that in the northeast there is a very great area, in the Dakotas and Montana, but that these areas decrease elsewhere in size, and that in Nevada and the western part of the arid region the coal areas, so far as they are known, are small. You will see them scattered about in various places on the map. (See map.)

This coal is all of a comparatively late age; that is, it is of a late age as compared with the coal of the eastern part of the United States. The coal of the East is of the Carboniferous age. The coal of the West is of the Cretaceous and Tertiary ages, but it varies in character very much. It varies from a brown, soft, friable lignite, found in many places, to the most valuable, dense, hard, anthracite.

Senator CASEY. Where are the anthracite fields?

Director POWELL. In Colorado, Arizona, and New Mexico, so far as I yet know. They may be elsewhere, but we do not know of them elsewhere at present.

All these coals are valuable for domestic purposes. They are all valuable for the creation of power by steam. A large part of them are valuable for metallurgical purposes. In this connection it must be understood that all coals, wherever found, present in each case a distinct problem for their utilization. When a new coal-field is discovered it is never known to what extent it may be used for metallurgical processes until experiments are made and a new method of coking is devised. A new method has to be invented for every new coal-field. A slight variation in the constant part, such as the bituminous or other quality, compels a change in the processes, and when a new region is discovered it is not known whether it is valuable for metallurgical purposes or not. This knowledge has been gathered now in the arid region. Ten years ago it was supposed there was only one field of coking coal in the West. One after another, however, the fields have been brought in as new methods were invented. I have no doubt that ultimately, as new methods are discovered by chemists and others, the fields of coal will one after another be brought in. In addition to that the fields of anthracite coal are being multiplied by discovery from year to year.

Senator CASEY. The gray lignites may be coked to advantage, may they not?

Director POWELL. Many of them may be. We have not discovered that all can be; but probably experience will prove that processes will be discovered for the coking of all gray lignites. It is doubtful about the brown lignites, however.

These coal-fields are very rich. They usually have from two to twenty and in some places even fifty beds of coal in one field. These vary in thickness from a few inches to 20, 30, 40, 50, and even 100 feet in some places. So that the coals are, for all practical purposes for our present civilization, inexhaustible.

These areas are such as, it is found by geological examination, are coal-bearing; but they do not always have the coal lying near the surface. In Dakota and Montana part of this coal-field is near the surface and part of it is deeper down at a depth of 2,000, 3,000, 4,000, or 5,000 feet, so that under present conditions not all of that coal area is available. The expense of getting at the deep coal is too great under present conditions in this country. But, notwithstanding all this, there is enough coal shown to exist near the surface in the hills, foot-hills, and mountains to give an ample supply for this country for many centuries.

The CHAIRMAN. They have some coal supply in the new State of Washington, west of the arid region, have they not?

Director POWELL. Yes, but you will notice that in these maps I have nothing to do with the humid region at all. There is a very valuable lot of coal in this space that I now indicate [indicating]. The red spots over the blue indicate the more important places where coal is mined; I could not get them all on this map.

Senator REAGAN. There are coal-fields in the Indian Territory and in northern Texas which are not shown on that map; but that is explained, I presume, by the fact that that region is outside of the line.

Director POWELL. Yes.

Senator MOODY. Have you had your attention called to the recent developments of those coal-fields lying west of what is known as the Black Hills?

Director POWELL. Yes; we are annually collecting the statistics of the coal mines. We have a corps of men engaged on that work.

Senator MOODY. Are you acquainted with the bed of coal that the Burlington and Missouri River Railroad people have been developing recently?

Director POWELL. Not from personal observation. I know it only by description.

Senator MOODY. Have any of your force examined it?

Director POWELL. Yes; they have analyzed it.

Senator MOODY. Is that what you call an upper bed, or is it a lower bed?

Director POWELL. The terms "upper bed" and "lower bed," as used by miners, have no special significance. The coal is Lower Cretaceous coal, but beds are tilted and brought up to the surface in various ways. In one district beds which are geologically low will lie high in the mountains, and beds a few miles away which are geologically high will appear in valleys, because the dipping of the rocks has so placed it.

Senator MOODY. You are aware, I suppose, that there is a very great difference between those strata of coal?

Director POWELL. Very great; but the difference does not in the least depend upon the geological horizon of the coal. The coals at Rock Springs, in Wyoming, belong high in the Cretaceous age and are very fine coals. The coals of the Sulphur Creek, 25 or 30 miles away, belong 5,000 feet lower in the geological series, and are not quite so good. In

other districts it will be *vice versa*, varying in character, and that variation is owing to the manner in which the coal beds are accumulated in basins.

Senator REAGAN. What are the brown spots indicated on the map?

Director POWELL. Those brown spots indicate the regions where coal is mined in large quantities for commercial purposes. I could not put all of them on the map. They are multifarious, but I put the most important mines in by dots on the map. (See map.)

Senator CASEY. Are there not extensive mining operations in Montana farther north than your map indicates?

Director POWELL. Perhaps there are, but the facts come to my office only once a year.

The CHAIRMAN. These coal areas may be found, on further development, to be larger than are indicated on the map?

Director POWELL. Yes. These that I show are the coal areas as they are known.

The map which I now place before you represents the drainage basins of the arid regions, and indicates to the committee the more important problems which have arisen in each one of these drainage basins represented on the map. For this purpose I will commence with the Arkansas basin, that is, I will set forth some of the more important problems that have arisen in the utilization of the Arkansas and its tributaries. (See map.)

This [indicating] is the basin as outlined on the map. The Arkansas River heads in the great mountains of central Colorado, in regions of perpetual snow, and flows down through the mountains until it debouches into the plains and runs through a great valley across the State of Colorado into Kansas and across a corner of Kansas down into the State of Arkansas.

The mountain region above is cold and inhospitable by reason of its great altitude. Great bodies of snow accumulate there during the winter and frosts may occur during any month of the summer. When it leaves the mountains and strikes the plains a warmer and more beautiful region is reached. In this upper region there are many beautiful valleys, valuable especially for pasturing purposes, and the mountains and hills on either side are covered with valuable forests. But when it reaches the plains it has a broad open valley for its course, and it is below where the waters are chiefly used for irrigation.

During the season of irrigation and in years of scarcity of water and small accumulation of snow, the entire volume of the Arkansas is now utilized. Any increase of irrigation on the Arkansas River hereafter must arise from the storage of the waters which now run to waste from nine to ten months of the year. The great body of the irrigable lands under canal ——

The CHAIRMAN. Let me interpose at this point just one question. Does not a large portion of the water run under ground in the sand?

Director POWELL. Yes. I will come to that point in a moment, if the Senator please.

Senator PLUMB. Speaking of the storage of water there, what is the actual average evaporation in that area each year?

Director POWELL. From standing bodies of water it will vary from 56 to 82 inches per annum, depending upon exposure to winds and upon altitude.

Senator PLUMB. What is the difference between the altitudes in that matter? Is there a greater evaporation in the lower altitudes?

Director POWELL. The higher the altitude the less the evaporation;

the greater the exposure to wind the greater the evaporation, and so on.

The Arkansas has irrigable lands, then, in the mountain region, but they are valuable chiefly for grasses. Below, on the Arkansas and on its tributaries—and what I say in relation to the Arkansas itself is practically true of most of its tributaries—the lands are situated somewhat lower than the land now irrigated in the State of Colorado from this river and its tributaries.

There is a very important and interesting condition which must be explained at this point, for it is a governing condition in the utilization of the waters of most of the rivers of the West. I wish to set it forth somewhat in full that it may be clearly understood. The waters of the West usually head in the mountains. The mountain streams are clear and deep, and in the main run in cañons. When the streams leave the mountains, and reach the plains or valleys below, their character is suddenly changed. The dry plains on either side are covered with dust, and the winds and storm waters blow and wash this dust into the stream. Thereupon, the river or creek immediately changes its character. While above, it was clear and deep and swift, below it becomes broad, shallow, and muddy. You are all familiar with the Platte River and know what the waters of that river are. It is a thin sheet of tawny mud, rolling down to the Missouri. Sometimes it is only 10 to 20 inches in depth, varying in places as you cross it. Nearly all the rivers of that country thus change their character when they leave the mountains, but there are important exceptions.

The point where this transformation occurs in the character of the streams is a critical and important point in the utilization of these waters. If the waters are taken out above this point they are used on land of less value by reason of climatic conditions, as already explained. If they are taken out below this point they are charged with silt and mud, and under these conditions they rapidly silt the ground and injure the lands on which they are placed, and they are especially bad in destroying the irrigation works. Water can not be taken out below this point because in some places the reservoirs will be filled up and the canals choked, and in other places they will be eroded and cut so that they are practically destroyed by the presence of the silt.

Senator CASEY. That is a matter of practical experience?

Director POWELL. Yes. So that it is always highly advantageous to take the water out of the stream at this critical point.

But, more than that; when the waters come down to this point they spread in valleys, like the Arkansas, 1, 2, 3, 4, 5, or 10 miles in width. A low sandy valley is found with a wide channel running through it; a low sandy "bench" on either side. Out into the sands on either side the water runs for miles and is rapidly evaporated, so that in a dry season no waters are used in irrigation. A large stream may come from the mountains of Colorado which may be lost before it reaches the Colorado-Kansas line, and no water whatever pass beyond that line.

In general there is a vast waste of the water in these sands. Only a part, however, of this water in the sands is evaporated; the other part remains in the sands. These sands can be tapped by wells and other methods and the water brought out on the surface, so that it is not all lost in this manner, although the larger part is lost by evaporation.

In the valley of the Arkansas irrigation commenced in the State of Colorado. The people of that region are anxious to increase the area of irrigation, and settlers are going into the upper creeks and into the mountains and upper valleys, and are taking out the water in those

upper valleys, to be used in the irrigation, in part, of hay-fields, and are raising some few other crops that may be grown in that cold climate.

Senator CASEY. Some wheat included?

Director POWELL. Not much wheat; the climate is almost too cold for that. There are some valleys where wheat may be grown, but not very many. The use of water in these upper regions is a great waste of the water, because of the climatic conditions, as I have explained. But a man may go on a stream above, and another farther up, and cut off the water from where it is used in the region below. It is a difficult matter, under the present laws of Colorado, to correct that condition of affairs, because it is difficult for the farmer in one county to enjoin by law the farmer above him in another county from using the water. How is he to say to the court that the water which the man above has taken is part of the water which he, below, should get for the use of his farm? Both are using the water that flows in the same stream. To identify the water used on a farm below is a very difficult matter. So that, at present, the tendency is to settle the mountain valleys, and thus to drive the agriculture of Colorado into the mountains, and away from the sunny valleys below. That tendency has only begun in Colorado; but elsewhere the evil is of great magnitude, and is accounted a matter of exceedingly great importance, and will, within the next five or ten years, become a matter of still greater importance to Colorado. The result is the driving of the people into the snowy mountains to live, instead of permitting them to live in the sunny plains below.

These problems that I have mentioned are inter-county, inter-community, and inter-farm problems. A new set of problems arises from the fact that the Arkansas passes the Colorado line into Kansas, and in Kansas the people have to resort to some extent to irrigation. In the past year they have developed some irrigation in that region. The water which they use flows from mountains far away; and the people of Kansas desire that the water shall be allowed to flow in its natural channel until it reaches their State, while the people of Colorado insist that they themselves have a right to the water in their State. This brings up an inter-state problem which has come to be a serious one.

Works have been constructed in Colorado, near the line of Kansas, and across the line in the State of Kansas, to irrigate lands to the amount of over 100,000 acres, and works are projected to be constructed this season, and are in part now constructed, to irrigate four or five times that amount. Should there be one, two, or three wet seasons on the upper Arkansas, and the present season is one of great snow-fall up to the present time, the river will supply water to those lands, but only on condition that it is not used above in Colorado. In this State, however, they are constructing works on a very much larger scale, and if these works are finished the waters of even a season of great precipitation will be used in Colorado, and no supply will be afforded to Kansas, except such waters as are taken from the sands of the valley.

Passing from the Arkansas to the Pecos we find problems of the same character. The Pecos rises in New Mexico and flows through a portion of Texas until it reaches the Rio Grande. This is the drainage basin of the Pecos, as shown on the map. The waters of the Pecos are now, and have for years been, used in New Mexico, in part, and to some extent in Texas. Within the last eighteen months or two years the development of irrigation on the Pecos, in New Mexico, has very greatly increased. There has been some increase of irrigation development in Texas, as the maps I have presented will show. There are companies at work this winter, with sufficient capital, engaged in the construction of canals in

New Mexico, and of dams, and to some extent of reservoirs, which, when completed, will take the waters of the Pecos, in New Mexico, and cut off the entire supply from Texas, and as the matter now stands all irrigation, ancient and modern, on the Pecos, will be swept out of existence in two years, unless some supply is provided other than that of the Pecos during the season of irrigation. It is, therefore, an inter-state problem. (See map.)

I will proceed to explain some of the problems which have arisen on the Rio Grande. For two or three centuries the Spanish people who settled on the Rio Grande have been irrigating the soil of that valley, and there are many Spanish or Mexican settlements scattered along its course. The Rio Grande heads in Colorado. It passes into New Mexico and runs southward across that State until ultimately it becomes the boundary line between Texas and the Republic of Mexico. It is in New Mexico, in Texas, and in old Mexico that this ancient irrigation is found. In modern times, or within the last five years, the waters of the Rio Grande have been taken out, and are now being taken out, in Colorado.

I am informed by the engineer of that region, who has just come here, and who has general charge of those works, that it is proposed, before the end of another season, to have canals and works ready for the irrigation of 1,500,000 acres, and that already works are prepared for the irrigation of more than 1,000,000 acres. The irrigation of that region and the waters of that region, in the main, are under the control of an insurance company, which goes into that region, takes out the water, establishes rights to the waters of the country, and sells those rights to the people and in part buys up the land, so that the company owns not only the water and distributes it to the people, but it in part owns also the land.

Passing into New Mexico, then, the water that practically heads in the high mountains of Colorado is largely, almost wholly, cut off from the Rio Grande, so that no portion of the water that heads in these mountains where there is a great precipitation will cross the line into New Mexico. Already the effect of that is seen in Mexico along the lower Rio Grande. During the past season the Rio Grande was dry for many miles below El Paso, which is situated near the line of New Mexico, Texas, and the Republic of Mexico. The Rio Grande was dry there, and dry for 360 miles above that point; so that the people of the lower valley of the Rio Grande in New Mexico, and the people of Texas below, and the people of the Republic of Mexico, had no water. The sand was blowing across the channel of the river, and instead of the space being covered by waves of water it was, when I saw it last, filled with sand dunes.

Senator PLUMB. Was not that due more to the absence of snow in the upper mountains at the head of the stream than to the taking out of the water from the upper stream?

Director POWELL. It is a complex problem. It is due in part to that.

Senator PLUMB. Has there not been a lack of snow during the last year, compared with former years?

Director POWELL. There has not been as much snow as usual.

Senator JONES. Is the Gila a tributary of the Colorado?

Director POWELL. It is a tributary of the Colorado.

The taking out of the water in Colorado subtracts from the river the volume of water which might come from those mountains. In a wet season there is water enough for all, as irrigation is developed to-day,

alike in Colorado, New Mexico, Texas, and the Republic of Mexico. But in a dry season the supply is entirely insufficient for all the lands now under canals. If in such seasons the water is used in Colorado and in upper New Mexico it is entirely cut off from lower New Mexico and from the valley of the Rio Grande immediately below El Paso. In a dry season nothing can be raised in the lower region, and sometimes dry seasons come two or three together. One dry season when lands are dependent upon irrigation is disastrous, because fruit trees, vineyards, and all perennial plants are killed. One or two such destructive seasons drives all the people away from the country.

Senator PLUMB. Is any part of that water returned to the river by seepage?

Director POWELL. Yes.

Senator PLUMB. What proportion do you know?

Director POWELL. About 50 per cent.

Senator PLUMB. About 50 per cent. taken from the canal would be returned to the river in the seepage?

Director POWELL. Yes, in careless irrigation. In careful irrigation, like that practiced in southern California, a much smaller amount is returned. With the best irrigation, none is returned.

Senator REAGAN. I put questions to some witnesses with regard to that return of water. It was stated that no provision of law had been made to compel persons taking the water for irrigation to return it to the river.

Senator PLUMB. The question I asked Major Powell was on a somewhat different line. I referred to the return of water by seepage, what would be returned to the river by soaking through the ground into the subterranean channels and be then returned to the river.

The CHAIRMAN. That water does not return or reach the river for the first year or two.

Director POWELL. Being asked by a committee of the Senate to investigate that subject I have for the last eighteen months been investigating it, and I have some facts to set before you in their order when I come to them.

Irrigation has also been greatly developed in New Mexico. The tributaries of the Rio Grande are being taken out in many places. Many streams are being taken out and the water spread upon the land. The Rio Grande is a clear stream until it passes Embudo Cañon, in northern New Mexico. From the mouth of the Chama downward it is a river of mud like the Platte, the Chama being also a river of mud.

Senator CASEY. Will you indicate on the map just about where that occurs?

Director POWELL. There [indicating on the map] is Embudo Cañon. It is a clear stream above that point; it is a river of mud below that. It is suddenly transformed, like the Platte, the Arkansas, and many other streams in the West. (See map).

Senator CASEY. That is after it has left the mountains?

Director POWELL. Below where it leaves the Embudo Cañon and receives the Chama. The water of the upper valley is being used to such an extent that the water of the lower valleys is being taken away from those who have been using it.

As long as no water is being stored in lakes, natural or artificial, or in reservoirs, irrigation in any district depends upon the flow of water through the season of irrigation. That season varies in different portions of the United States from a little less than two months to a little more than three months. Perhaps on the Lower Colorado it will be five

months, but in general it varies from two to three months. The irrigation practiced in this manner has a practical limit placed upon it by the dry season. For if in seasons of greater humidity larger areas are brought under ditches, when seasons of greater dryness or aridity come the farmers depending on such waters are destroyed. The trees and vines that are growing become dried up and the seeds go to waste and the canals are filled with sand by the winds. The limit of agriculture is set by the dry season. Hence it may happen, and will happen on the Rio Grande and elsewhere, that in seasons of great humidity there will be sufficient water flowing during the season of irrigation to supply the wants of all the people now engaged in irrigation there and of the people who will want water under the works projected during the past year. But during the season of drought the amount of water is insufficient to serve the land already provided with canals.

A part of the waters that are spread upon the land are returned to the rivers, as shown by the investigations that your committee have been making this year. We have in Colorado and elsewhere studied certain streams that were all taken out and spread upon the land. We have measured the waters thus spread upon the land while being spread. We have then gone below, where these waters have been recovered—where the waters flowing from the irrigated land have been used again—and we have measured the waters thus used again, and have found that the conditions for the recovery of the water vary greatly; that they vary greatly for very important reasons; that in extreme cases 70 per cent. of the water returns to channels immediately below the place where it is used, and 30 per cent. only is evaporated. But that is under conditions where an excessive amount is put on the lands by the farmers.

Growing plants evaporate three hundred times their own weight of growth annually. Whatever the crop may be, whether corn, grass, or wheat, that grows in one year, it will evaporate into the heavens three hundred times its own weight of water. If, then, a crop is raised on a field which is irrigated, and a farmer is careless to such an extent that the field is covered not only with the corn or other crop he desires to raise, but also with a dense growth of weeds, the evaporation from that surface will be enormous. But if his field of corn is well cultivated, and if speedily after each irrigation he turns, with a harrow or raking tool, the ground between the rows, so as to have the ground mulched with a thin surface of soil, the evaporation is at a minimum. The great duty of water which they have secured in Southern California is secured by perfect cultivation, but when the cultivation is bad it requires two or three times the amount of water that is required when the cultivation is good.

There are some other conditions affecting the return of the water besides the two mentioned. Something in the nature of the soil and something in the condition of the slopes determine how much of this water can be recovered, but under the most favorable conditions we find that about 70 per cent. can be recovered to be used again. Under some conditions, however, only 30 per cent. can be recovered. That depends in part on the condition of the slope, in part on the subsoil itself, and in part on the condition of the soil, as well as on the conditions of the channels below in which it may be gathered. Under the best conditions and with thorough cultivation nothing is returned.

The CHAIRMAN. Is there not another condition—the condition of time when getting the ground saturated in the first instance?

Director POWELL. Yes.

The CHAIRMAN. We had an illustration of that at Fresno and other places.

Director POWELL. Yes; and it is universal. It will be noticed all over the country, where it is properly studied. A very large amount of water is necessary to saturate the soil the first year. The maximum duty of water is not reached until two, three, four, or five years of cultivation have been had. So that the claims which the people set up to the amount of land which can ultimately be redeemed by the irrigating works already constructed are well maintained by the fact, because although to-day the water may be used to the utmost extent, next year larger areas can be irrigated, and the year after still larger areas, and this for a term of years will increase until after a few years the whole duty of water can be secured. When the whole duty of water is secured, the land well cultivated and economically irrigated, but little will return to the streams.

In the valley of the Rio Grande the greater portion of the water during the season of irrigation is lost in the sands, as in the valley of the Arkansas. If the water of the Rio Grande is compelled to flow across the line from Colorado into New Mexico, it will destroy from 1,000,000 to 1,500,000 acres of agriculture above, in order to save 200,000 or 300,000 acres in the valley below. The water can not be used below for the benefit of the greatest number of people. It is important that irrigation in Colorado which is already established and in progress of establishment should proceed.

But what remedy have the people below to save their property from destruction? The lateral streams which come in are being taken out above in the same manner. Some provision ought to be made by which the waters of these lateral streams, and the waters which flow into the Rio Grande below the Colorado line, should be made first to serve the irrigation already established. As the matter now goes on the new irrigation is destroying the old. When we come down to El Paso we find mountains in that neighborhood the waters of which are competent to serve all the lands on the Texas side and on the Mexican side if they can be utilized—if they can be stored. The waters which can be stored in that region are ample for that purpose, but all the storm waters of the immediate region must be stored.

The CHAIRMAN. You would add to that the flood waters that come down every winter?

Director POWELL. I am supposing that there will be no flood waters in dry seasons when the water is properly used above. The people will become better skilled in using the water and there will not be so much waste of the flood waters.

The CHAIRMAN. Do you think it would be a possibility to use all the flood waters?

Director POWELL, I think ultimately it would be possible to use all the flood waters. I think the waters which flow from the mountains of New Mexico are ample to supply the irrigation already established and much more.

Senator PLUMB. What is the valley area of the Rio Grande above this cañon which was spoken of a while ago?

Director POWELL. The Embudo Cañon?

Senator PLUMB. Yes; give us a rough calculation as to that.

Director POWELL. Roughly speaking it would be 5,000,000 acres above Embudo Cañon, good and bad. It is estimated by an engineer of skill and ability that about 1,500,000 acres can be redeemed by irrigation there.

Senator CASEY. The conditions are such as you spoke of a while ago—the land not being adaptable, you think, to cereals.

Director POWELL. Oats and wheat can be raised there but not corn. It happens to be just in the border region between the upper and the lower climates.

Senator PLUMB. Then your opinion is that all the waters that originate either by creeks or otherwise and all the storm waters of that area will be used within the area when this maximum of irrigation is reached.

Director POWELL. That is my judgment.

Senator PLUMB. And then that there will be no water to be utilized in the lower Rio Grande.

Director POWELL. None from this source.

Senator CASEY. Especially if they raise wheat.

Senator PLUMB. They can raise fine potatoes in that country too.

Senator CASEY. There is not the same salability for potatoes.

Director POWELL. Serious troubles are arising in the Rio Grande Valley now and the valley is all aflame. The people are petitioning the Secretary of the Interior and the Secretary of War for troops to protect the old rights from invasion by those who are developing new systems in that country. The difficulty is that at present there is no way by which any court or authoritative officer can say whether a canal shall or shall not be constructed. There is at present no determination of specific waters to specific lands and the area which it is possible to irrigate is six or twelve times as great as the waters will ever serve. What is needed is something by which somebody may be able to say that the waters shall be used on particular lands, so that the valley shall not be left open for anybody to construct a ditch above that of his neighbor and take away from him the water that he has been using. That is the same problem that has arisen on the Pecos.

The CHAIRMAN. What would be your suggestion as to saving the lower waters for the benefit of those people in the Republic of Mexico and in Texas?

Director POWELL. I think a reservoir can be constructed at El Paso. I have had a reservoir planned, and have had the surveys begun in that region, so as to discover the areas that would drain into it, the amount of water in the catchment area, and the amount that would accumulate in the immediate region if it were all cut off above. I find already that there is a large flow into the river in the immediate neighborhood sufficient to fill a great reservoir there which, I believe, would support all the irrigation which has been already developed along the lower river. The catchment area is not fully surveyed; its extent and the character of its slopes are not fully determined; and I can not yet say how much water can be caught.

The CHAIRMAN. Would it be enough for an addition of some new land on the Texas side?

Director POWELL. I believe it would.

The CHAIRMAN. You have stated that it was difficult to have reservoirs on the lower levels. How would you free that reservoir from silt? Would that be practicable? Have you considered that question?

Director POWELL. Yes, I have considered that question with great care. That seemed to be a serious problem. If the reservior is to depend on the bed of the river it is one problem; if on the mountains adjacent it is another problem. If it is to take all the silt of the river, and the waters are not cut off by irrigation above, it will fill in about one

hundred years if the flow of the river should be continued for the future as it has been in the past. We have measured the silt of the river from day to day for some months so as to determine that question. There is another source of débris in the hills and mountains that stand about the reservoir sites, the amount of which is yet undetermined, and can not be until the topographic survey is completed.

The CHAIRMAN. Has any method been discovered or devised whereby to free the reservoirs from silt?

Director POWELL. Yes; but nothing that is not somewhat problematical as yet. If filled by the brooks and creeks that flow from the adjacent mountains it can be constructed with dikes or wings on either side so that every stream can be checked on the bench above before it is turned into the reservoir and its flow turned around a long course, and it may be thus forced to deposit its silt on the benches above so that the water can come into the reservoir itself comparatively pure. The reservoir under those conditions would be comparatively permanent. It would last two or three hundred years if the silt above were cut off.

The CHAIRMAN. What would be the probable cost of that?

Director POWELL. I have not the figures before me at the moment and I dare not speak from memory. I have the figures at my office. The construction of the reservoir might be the minor cost. The right of way might be the major cost, because two railroads run across the site.

Senator REAGAN. Regarding the exhaustion of the waters of the Rio Grande, the people tell me that during the flood season the Rio Grande is very great in size.

Director POWELL. It is.

Senator REAGAN. And that it carries a great volume of water. Is it likely that that water could be so stored that it would not flood the country?

Director POWELL. In my judgment it is likely that that can be done in time. It is my belief that it is possible to store all the waters of the Rio Grande in lakes; cut off all the tributaries from Colorado down to the Texas line; and if all the tributaries are cut off and the water of every tributary is stored there is very little water for the valley of drifting sands. But that will not be done to-day or next year. It may be twenty years before all the water is stored. If, however, irrigation should develop for twenty years as it has developed for the past two years in that country the water will all be cut off in less time, that is, all the flood waters of the dry season.

Senator REAGAN. If storage would do they might get the waters of the wet season and hold them over for the dry season.

Director POWELL. Yes, that will ultimately be done, to some extent.

Senator PLUMB. When you say "season" do you mean "year?"

Director POWELL. Yes, I mean the dry year. I think the waters will be ultimately stored in that region. They are already in that region providing reservoirs to store the water and hold it over from the wet year to the dry year.

Senator CASEY. Have you formed any estimate as to the number of dry years in a number of given years?

Director POWELL. They will come pretty evenly. There will be two or three or four years dry, and two or three or four years wet; not invariably so, but frequently so.

I place before you to-day a map of the Rio Grande, including all the area drained by that stream north of the Texas line. There are some

important facts relating to the utilization of the arid lands which can be well elucidated by considering that region of country, and I present the map again for that reason. In talking to you about the irrigation problems presented in the valley of the Arkansas, I called your attention to the fact that that valley could be divided into districts, each one an independent unit. The whole arid region may be divided in like manner into natural districts or drainage basins, each one of which has its problems so interwoven that the entire district must be so considered in planning its system of irrigation works, but which is practically independent of all other districts. These hydrographic basins, as I call them, are of three classes, viz, headwater districts, river-trunk districts, and lost-stream districts. The headwater districts commence in the mountains and extend down the streams far enough to include catchment areas and farming areas. These headwater districts are not only found on the main streams, but on all perennial laterals or tributaries. Usually each lateral or tributary forms a natural district by itself. But the great rivers flow on across the plains and down the great valleys, and their trunks must be divided into districts, each one of which presents an independent system of works. These I call river-trunk districts. Then in the arid lands there are many streams which do not flow into great rivers and ultimately to the sea, their waters being lost in the sands or emptying into salt lakes. These I call lost-stream districts. All of these classes are represented in the Rio Grande region, the map of which is before you.

In considering this subject and planning the work of the Irrigation Survey, it has been found that a natural district or hydrographic basin must be considered as a unit in which all the problems must be solved. In order to report upon the district and recommend a plan of works, we must know in such a district how much water will be supplied for irrigation where the diverting dam sites, reservoir sites, and canal sites are situate and where the lands to be irrigated lie. And it has been found, after a careful examination and from the best data we have on hand, that there will be two or three hundred such districts in the arid region, and that if the survey is carried out it will need a separate report on each. I have therefore found it necessary, for the administration of the Survey, to consider these hydrographic basins, and have been studying them for some time—in fact for years before the survey was organized, for I early recognized that ultimately these natural features would present conditions which would control the engineering problems of irrigation and which would ultimately control the institutional or legal problems. The study which I have made in the survey in this direction of course can not be considered final. An actual survey on the ground is necessary to define the limits of each basin, and a very careful survey is especially necessary to define the limits of the trunk districts. The headwater districts, or those of the first class, and the lost-stream districts, or those of the third class, are quite easily discovered; but the districts of the second class require very careful study for their determination. The meaning of this will more fully appear from the illustrations which I am able to present to you to-day in considering the Rio Grande Valley.

First, we have the Saguache River, a river with tributaries—a number of beautiful creeks. The river flows into a sink, and the drainage is lost in the sands. Now, the utilization of that water affects that valley only. It is independent of all the other regions of country. The region of country at the sink is one of sand, and it sinks in these sands and is evaporated. It is only on very rare occasions, many years apart, that

there will be a great flood which will cause it to overflow and open a channel to the Rio Grande. In all ordinary years all the water which is used must be in the valley here [indicating], hence it is an independent basin. This is what I call a district of the third class, a lost-river district. It will be noticed that in this district the people who engage in agriculture here can not possibly have any conflict about water rights with the people of any other district. They may use all of this element which they can catch and spread it upon their lands, and nothing will be cut off from any other district; nor can they obtain water from any other district to put upon their lands. And they are interested not only in the water; they and they only are interested in the forests about the fountains whence their waters come, and they are the people who should be interested in the grasses which grow in the valleys and on the hills and mountain slopes.

The Saguache district, therefore, is clearly defined in nature. Its boundary is marked everywhere by the parting of the waters.

Passing over to the Rio Grande proper, we have the San Luis district, which is also a headwater district. The San Luis park is a beautiful tract of land, and high mountains stand around it and gather great quantities of water. This is a region lately redeemed for agriculture, but already all the flow of critical years with extreme dry seasons is used in agriculture, and the companies that are specially interested in these water rights are preparing to store and use all its waters which flow through this season. It may be possible that they can use all and that the area of good land to be cultivated will be sufficient. We do not yet know the amount of water that flows in the streams, nor do we know the amount of good available land. Be that as it may, we are able to state that this great district is a unit, and that it must be considered as such in planning the proper system of irrigation works, and that its people will be as a body interested in the management of its waters, its forests, and its pastures. And they are the only people to be interested except to this extent, that if the waters are not used here they will flow into trunk districts below, to be used there. If the people of the districts below, in New Mexico, could lay an embargo upon irrigation in the San Luis Valley, larger areas in New Mexico could be cultivated, but the loss of water on the way would be such that they would not equal in area the lands that could be irrigated in Colorado. It is therefore manifest that it is to the advantage of the agricultural interests of the country that the people of Colorado who live in the San Luis Valley should be permitted to develop their agriculture to the utmost, and use all the waters that they can put upon good agricultural lands.

The Rio Grande, in crossing the line between Colorado and New Mexico, enters a cañon and flows for about 50 miles through the gorge, and its waters can not be taken out along this stretch. This cañon ends where Taos River, coming from the east, joins the Rio Grande. The Taos is a beautiful stream and all of its waters can be used in its own valley. All that run during the season of irrigation and all that run throughout the year can be stored, so that the waters of the Taos may ultimately be cut off from the Rio Grande.

The region of country on either side of the cañon of which I have made mention—Embudo Cañon—has lava-fields and is not agricultural; but some fair timber grows there and much water comes down into the cañon, so that when the river emerges into the valley at the foot of Embudo Cañon it is a fine stream, and must always be so whatever water is taken out in Colorado above. Some 40 or 50 miles below the river enters another cañon. Between these two cañons lies the valley of San

Ildefonso, into which come some small creeks from the east, and the water of the Rio Grande can be taken out at the foot of Embudo Cañon and spread over the San Ildefonso Valley and make here a river trunk district, or district of the second class. This is a district also well defined in nature. Its catchment area is lava-fields above and mountains on every hand, and its irrigable or farming area is the low valley stretching back from the Rio Grande on either side.

Near the foot of San Ildefonso the Chama enters from the west. The Chama is a large river for that country, and its smaller tributaries drain great mountains, and there are many beautiful valleys scattered about through the region. The lower portion of the Chama runs through a sand plain, and these sands are volcanic ashes which drift and blow into the river and fill it with sediment. The Rio Grande above the mouth of the Chama is a clear, beautiful river, but at the mouth of the Chama it is transformed by the mud of the Chama itself. It then becomes a river of mud and continues such to the Gulf, as it takes up sands along its way. The Chama Basin is another natural basin, having timber lands, pasturage lands, and agricultural lands.

At the foot of San Ildefonso Valley the Rio Grande enters White Rock Cañon and continues its course through a deep gorge for 40 or 50 miles. Along this course its waters can not be used for irrigation. The cañon walls are hundreds of feet, and in some places more than a thousand feet, above the waters. But the high volcanic plateau on the east furnishes a notable amount of water to this stream, and on the west there is a group of great volcanoes from which many beautiful streams flow; so that if all the water should be cut off at the head of White Rock Cañon, there would still come into the Rio Grande, through the course of this gorge, a vast body of water to be used below —water which can not be used elsewhere, as none of the streams above on either side of the cañon have agricultural lands along their courses. But they have great forests. Here some of the finest forests of New Mexico are found. This is the great catchment area for the valley below White Rock Cañon.

Some flood waters will always come down the Rio Grande from San Ildefonso Valley, however thoroughly the country may be utilized, and additional water will be caught in the cañon itself, and so the valley below will have a good supply. White Rock Cañon empties below into a valley which I shall call the Albuquerque Valley. In it lie Bernalillo, Albuquerque, Los Lunas, Socorro, and other towns. Now, all the water that comes out of White Rock Cañon can be used in the Albuquerque Valley, as it may be diverted below the White Rock Cañon and carried out and stored on the flanks of the valley. There is now much agriculture in this valley, and some of it is very ancient. Including the catchment area about White Rock Cañon and the hills and mountains on either side, and the valley where agriculture can be carried on, we have another natural district or hydrographic basin—a district of the second class, or stream-trunk district. Now, it will be seen that all the water to be used in this great valley comes from the mouth of White Rock Cañon. Whoever has control of that point owns that dam site and has the right to take the water out of its natural channel and carry it into canals—has command of all the agriculture of that great district.

I wish to explain further that the people who have settled here have taken out the waters of the Rio Grande and utilized them during the season of irrigation, but they have not yet resorted to storage and the waters which they use are used to very poor advantage. The flood plain or strip of country next to the river which is sometimes overflowed is

broad and sandy; the river itself is shallow and is a river of mud, and it is very wide; so it flows into these sands and is evaporated to a very large extent and thus lost to agriculture. Then the people have constructed low-lying ditches near to the Rio Grande and take out the water by a system which is exceedingly wasteful and which is destroyed more or less with every flood. Ultimately they will find it to their advantage to take the water higher up, near the mouth of White Rock Cañon, and carry it out by high line canals and store the surplus in the lateral valleys. By this means the area of agriculture in the valley can be increased five or ten fold.

It is possible to take all the water of the Rio Grande there during the season of irrigation. It is also possible to take out all the water there during the non-irrigating season. If the water for the non-irrigating season is to be stored, you are compelled to take it out there. You can not take it out by the present ditches, for they do not flow on high enough ground; but if a canal is constructed from the mouth of White Rock Cañon, and a diverting dam built there and lakes made—there are good places—all the water could be used in the valley. So, not only is it necessary to take the water out at that one point and utilize the entire flow during the season of irrigation, but it is also necessary to take it out at that point in order to store the water which now runs to waste. So that if the water is taken out at this one point of which I speak altogether, the area of irrigation will be multiplied ten times. But that can not be done without considering the rights of the people who now use some of the water by improvident and obstructive dams.

Off to the east here, as you see on the map, is the Santa Fé Creek, on which the city of Santa Fé is situated. It also constitutes a distinct basin with irrigable lands, timber lands, and pasturage lands, and all its waters can be caught and used in the Santa Fé Valley, so that no considerable amount will ultimately flow from the Santa Fé Creek into the Rio Grande.

On the west we have the Jemez River, where another natural district of the first class is found. The Jemez River drains the Tewan Mountains and plateau. The catchment area is well wooded. Fine forests are found and great mountain meadows are seen, but the land above is cold and is not valuable for agriculture, except for pasturage, and perhaps a little hay may be cut with advantage. The many streams which head in the Tewan Mountains and plateau find their way into deep cañons. On leaving the mountains nearer Jemez Pueblo the whole body of the stream can be taken out and put on the mesa above Albuquerque, or west of Albuquerque and Bernalillo. It is another natural hydrographic basin of the first class.

Below Albuquerque we have the Rio Puerco. All of its waters can be used in the upper portion of its valley, and there is much more land than the water will serve. Very little water ever runs into the Rio Grande from the Puerco, and that comes only at flood-time. It is a hydrographic district of the third class, with irrigable timber and pasturage lands, and with many fine sites for reservoirs.

Where the Albuquerque district should end and the next district embracing the Mesilla Valley and the El Paso Valley should begin, I am not able to state, but from such information as I have been able to collect, I believe that below Socorro a new natural division can be made.

Let us go on to consider the region of the Rio Grande below, from Socorro to a point on the river 30 or 40 miles below El Paso. Here there are two valleys, Mesilla Valley above El Paso and the valley be-

low, a part of which is in the Republic of Mexico and a part in Texas. Now it is possible to cut off from these two valleys all of the waters which flow during the season of irrigation in critical years and destroy all the agriculture in those two valleys unless the waters of the non-irrigation season are stored. During the non-irrigating season large bodies of water come into the Rio Grande from the mountains on either side. There are high mountains to the west and high mountains to the east, but there are few perennial streams, and they are only small creeks. The principal body of the water comes in as storm water. But the area is pretty large and its waters can be stored immediately above El Paso and at the head and along the flanks of the Mesilla Valley. At the Point of Rocks, at the head of Mesilla Valley, all of the waters of the Rio Grande can be captured again and they can be taken out into the Mesilla Valley and used once more.

The waters of the non-irrigating season can be stored on the flanks of the valley, and there is more land than all the waters will serve. Still there is a mountain catchment area on either side of the Mesilla Valley, the waters of which will flow through the valley at El Paso at flood times, and these waters can be stored to be used in the valley below in Texas and Old Mexico. But I do not think there is enough of these waters to support all the agriculture now developed if the waters of the Rio Grande are all taken out at the Point of Rocks. To maintain the irrigation now developed in the El Paso and Mesilla Valleys, some division of the waters must be here made. The catch from Socorro down, coming from the mountains on either side, and the surplus which may come down in great floods from the Rio Grande above, must be divided between the Mesilla Valley and the El Paso Valley to maintain the agriculture already established and to give some development to the same. Just how this can be done to advantage is not known; the topographic survey has not proceeded far enough. We know where the waters can be stored for the El Paso Valley, and I have already explained that to the committee some days ago. We can create a great reservoir with reasonable economy immediately above El Paso; we can also create a reservoir, or series of reservoirs, in the Mesilla Valley; but how much water can be caught and held in these reservoirs we do not know, and can not know until the topographic survey is completed, for on that we depend to determine the water supply.

It is safe to say, however, that the reservoir at El Paso may be constructed, and I incline to think that the rights to the present irrigation in the Mesilla Valley may be maintained, the rights in the El Paso Valley maintained, and that irrigation in both districts may be increased—but to what extent and to what size these reservoirs should be constructed is yet unknown. It will require another year's survey to determine these facts. This, however, is certain, that there can be no development of irrigation in these valleys through the use of the waters of the irrigating season only; in fact the present agriculture can not be maintained unless the waters are stored. The irrigation already developed in Colorado and the upper valleys of New Mexico is destroying the agriculture here. Two more years of development will cut it all off when dry seasons come. The only hope for these valleys is through storage, and how the entire problem is to be solved by storage is not yet known. Nor can it be done without some interference on the part of the United States. If the General Government does not step in and by definite legislation assign specific waters to El Paso and the Mesilla, the El Paso Valley will surely be destroyed, and the Mesilla Valley can be almost ruined by the people of the Albuquerque

Valley. What is needed is the construction of storage reservoirs and their protection, and the assignment of specific catchment areas to those reservoirs. The Government must say that a certain catchment area can be used for the Mesilla Valley and that the remaining catchment area can be used for the Albuquerque Valley.

A State, a Territory, and a foreign country are involved, and they can not settle the problem for themselves. There is only one way to protect this ancient irrigation in the El Paso and Mesilla Valleys and their right to use the water of the irrigating season, and to proceed as they have heretofore done without storage, and that is to destroy all irrigation in Colorado and all of the lately developed irrigation in the valley of the Rio Grande in New Mexico above, and to prohibit forever the use of the waters there; and this would mean that to maintain seventy-five to one hundred thousand acres of agriculture, several million acres of development must be stopped. Of course this can not be done. They must resort to storage, and somehow storage rights must be fixed and maintained.

The area drained by the Rio Grande above El Paso is a little more than 23,500,000 acres, or about 37,000 square miles. But much of the region is mountainous. Even if there was water enough it would not be possible to irrigate one-half of the land; of the arable lands only a portion are irrigable, from the fact that there is not water to supply them all. It may be that when all the waters of the Rio Grande are used in Colorado and New Mexico and in the valley of El Paso, in Texas, and the Republic of Mexico, from three to four million acres can be cultivated; but this can be done only by using all of the waters and storing all those that now run to waste. And then the irrigable lands must be properly selected, so that the waters can be used to the best advantage. That none may be wasted they must be stored where there is the least evaporation, and the lands must be selected near where they are stored, and the waters must not be permitted to run through sand valleys, where they are evaporated. They must be taken out from the streams and stored to the best advantage and used without waste. Then it may be possible to irrigate from three to four million acres. Of course the estimate is rough, because the surveys have not been perfected, and it may be too great; I do not think it is too small. Now the problem which you ask me to solve is this: How can these waters be used to the best advantage; how can they be divided among the best lands; and how can the rights of the present irrigators be maintained? I shall try to answer these questions, and certain collateral problems that are involved; and to do so, shall go over the the ground again, district by district.

Commencing then at the head of the Rio Grande Valley, we first meet with the Saguache. This river sinks in the sands; except in very great floods it discharges no water into the Rio Grande. Its valley therefore is an independent district, one of the minor class; all that can be done in the Saguache district is to select the best irrigable lands and provide that the waters shall not be used where they will be largely wasted.

Then we have a district drained by the headwaters of the Rio Grande—a district of the first class. All or nearly all of its waters can be used within the district on good lands, but they must be selected or the waters will be wasted. The district lies wholly within the State of Colorado.

The next district below on the river is the San Ildefonso. This is a trunk district and thus belongs to the second class. For 60 miles down

below the Colorado line the river can not be taken out, as it runs in a cañon. The lands on either side are of little value and should be used only for pasturage and forest purposes. This upper portion of the San Ildefonso Valley is naturally the catchment area for the waters to be used in the valley below the mouth of Embudo Cañon. There are some creeks that come into this valley from the mountains on the east. This district, therefore, has a great catchment area which will supply a large quantity of water, which should be dedicated to the use of the farmers of the valley below. But they should understand that they can not maintain rights to use water coming from the San Luis district; that they should develop their agriculture wholly from the supply of their own catchment area. The best lands lie on either side of the river in the valley below Embudo Cañon and along sections of the eastern tributaries. These lands should be selected in sufficient amount to use all the water for irrigation, then there could be no controversy about the water rights in the district. Settlers could not go upon the non-irrigable lands and illegally take the water; farming could be developed in the valley to the greatest extent and on the best lands, and the farmers would be secure from depredation by other farmers going above them and pirating the water—to use a term common in the western country.

Midway in this district, and at the head of the irrigable lands, the Taos joins the Grande. It is a fine stream and its drainage basin constitutes a district of the first class. All the waters of the Taos can be used in its own valley, and it should be established that the people of that district have a right to use all of those waters, and that the people in the San Ildefonso Valley below can never maintain the right to have those waters flow down to their valley; that the Taos Valley is not a part of the catchment area of the San Ildefonso Valley.

In the lower part of the San Ildefonso Valley the Chama joins the Rio Grande. The basin drained by this river constitutes a district of the first class. All its waters can be used at home, and it should be established that the people have a right to use them there, and that no right can be maintained to the use of its waters outside the district.

At the foot of the San Ildefonso Valley the Rio Grande again enters a deep cañon for a course of 50 miles. Along this course it receives many important tributaries that drain high mountains, and on these and timber region, and is a catchment area for a district below. The irrigation can not be practiced to any advantage. It is a pasturage cañon is known as White Rock Cañon. At its mouth the waters can be taken out again and spread over a large valley. In this valley there are already a number of considerable towns. Albuquerque is the principal city, and we will call it the Albuquerque Valley, and the district, including the valley and the catchment area above, the Albuquerque district. It is, of course, a trunk district, and hence belongs to the second class.

Now, it should be established that the people of the Albuquerque district can not maintain rights to use water not caught within their district; that all the volume of the Rio Grande in the San Ildefonso above belongs to the people of that valley; that the only waters which the Albuquerque farmers can use and permanently maintain rights to are those falling from the heavens over their district. The irrigable lands of the Albuquerque district are in excess of the water supply. The nearer to the mouth of the White Rock Cañon they can be used, the greater the area that can be irrigated. Perhaps this district should terminate at Socorro. Perhaps it should go down to San Marcial. A careful topographic and hydrographic survey is necessary to determine

this boundary. The district would, at any rate, be more than 150 miles in length, and it is a long sand basin. If the irrigable land should be selected in the southern end of the district, much of the water would be lost on its way; if it is selected in the northern end of the district, this water could be saved. The Rio Grande will irrigate 200,000 acres in the northern end of the valley. But there are lands already irrigated in the southern end of the valley and their rights should be maintained, at least until they are justly extinguished. Doubtless this will ultimately be done. It is of prime importance that no more rights be established in the southern region of the district.

To the east of the White Cañon lies Santa Fé Creek. It is a beautiful stream of water and the region which it drains forms a district of the first class. Here the city of Santa Fé is situated, and the waters of the great creek are all used in irrigation during the summer months. An attempt has been made to store water, but it has proved a failure. The site of the reservoir was among hills that had been denuded of their forests and grasses, and the reservoir was destroyed by the enormous and rapid accumulation of debris. Other and better reservoir sites have been found where the forests are not yet destroyed. The farmers of the district should have control of these forests, or they can not greatly increase the area of irrigation in the district. The lands to be irrigated lie on a plateau in the neighborhood of the city and are already of great value. The principal catchment area is in high mountains where there are extensive forest lands and where there should be pasturage lands, but these are largely destroyed by over-feeding. The pasturage and timber lands greatly need protection in the interests of agriculture below.

Just above Bernalillo the Jemez joins the Rio Grande, and here we have another district of the first class. The Jemez now discharges a part of its waters into the sand, for there is a long stretch of dunes extending from Cia down to the Rio Grande. Still the river has a volume sufficient to carry part of its waters over the sands and discharge them into the Rio Grande. The catchment area is the Tewan Mountains and the Tewan Plateau, a lofty region covered with beautiful forests and the rich grass lands yet uninjured by fire or over-feeding. The mountain meadows are abundant and beautiful, and the forests are among the best in New Mexico. The lands to be cultivated by this river lie on the mesa west of the Bernalillo and Albuquerque. The waters can be stored in the mountain meadows and elsewhere very cheaply, but it will be expensive to take the water across the sand dunes on to the irrigable lands of the mesa. The mesa itself and the catchment area both should constitute one district. The waters of the mountains should be attached to the lands of the mesa, and the right to use the water should permanently inhere there. The settlers in the valley of the Rio Grande should not be able to acquire rights to the waters, for in so doing they will be chiefly wasted. The catchment area is a volcanic district, and volcanic cinders and ashes abound; and these conditions make it necessary to carefully protect the lands, otherwise they will sink the streams and fill the reservoirs. The forest area is, therefore, chiefly valuable as a catchment area, and which should never be denuded of its trees.

The next stream is the Puerco, which comes in below from the west. It heads in the Nacimiento Mountains, on the western slope of the Tewan group. Along this range of mountains there are several beautiful streams that flow into a distant valley into the channel of the Puerco and here land in the sands and pass only in extreme floods into the

lished. These obstructive rights are of two classes. First, where a lateral stream joins a main stream, the waters of the lateral should be taken to lands sufficiently high up its course to be out of the way of the development of irrigation on the principal stream.

The principal stream usually has a lower gradient, and its waters can not be taken to very high lands; and if the waters of the lateral stream occupy the low lands, the waters of the principal stream can not be used. This condition of affairs has arisen in many cases already in the development of irrigation in the West. The obstructions of the second class relate to low line canals taken out along the course of the stream which runs in a sand plain. If the canals are taken out here, the whole length of line is extravagantly great, and the loss of water is correspondingly great. All canal lines which relate to the utilization of water for irrigation and to the development of agriculture in arid lands—they are all of great importance; no one can be neglected without doing serious injury to agricultural industries. If these things were done in advance of more dense settlement, and then the people permitted to control their affairs in their own way—divide the water among themselves in each district as they please, protect and utilize their forests in obedience to their own judgment, corrected by experience as time goes on, use the pasturage for their flocks and herds, and protect it from destruction that they may thus use it, the arid lands would furnish homes to prosperous, peaceful, and happy people.

Senator PLUMB. Are you going to deal with the question of the underflow or subdrainage? I wish to ask you some questions in regard to that.

Director POWELL. I am ready to answer any question at once, so far as I am able.

Senator REAGAN. That subject will come in better order when he comes to discuss the Gila River.

Senator PLUMB. Very well.

Director POWELL. The Gila heads in the mountains in the eastern part of Arizona and in New Mexico, but the main part in northern Arizona. Running along this line in Arizona there is a line of cliffs rising from 2,000 to 5,000 feet high, so that the region above is from 2,000 to 5,000 feet higher than the region below. This [indicating by the map] is the plateau of Arizona and this the lowland of Arizona. There is a general difference of altitude of 3,000 to 5,000 feet. The streams all head on this plateau or in these high mountains, and as they flow westward, to unite with the Colorado, every stream becomes generally less and less, so that while there may be in dry seasons a great body of water coming from the plateau and the mountains and there may be scores of beautiful creeks and some small rivers that are perennial (even in the dry seasons), yet in dry seasons the low part of the Gila will be a series of sand hills. (See map.)

Senator CASEY. In the dry season of every year?

Director POWELL. It is only in the very wet years that there is water running in the Gila during the dry season.

Senator CASEY. The dry season of the average year?

Director POWELL. In the dry season of the average year the lower Gila is dry. The rain-fall above is 20 inches or more, and in the mountains it may be 24 inches in some places. Below, the rain-fall is from 3 to 10 inches only.

Senator PLUMB. Where does the rain-fall come from in that region? Is it from local evaporation?

Director POWELL. Partly so, but in the main most of the moisture of this region comes from the Pacific Ocean and Gulf of California, though it is used over and over again. It is evaporated and then falls, is again evaporated and again falls, and so on. It is used over and over again in that manner as it passes eastward with the great upper currents of air.

Now, in all these mountains and cliffs from which beautiful streams run out many are found which never reach the Gila at all.

Senator PLUMB. Is that not a feature of mountain drainage everywhere, as in the upper Rocky Mountain region, for example?

Director POWELL. It is common but not universal. It is a special feature of this region.

Senator PLUMB. I have seen many streams in the Rocky Mountains that were rushing torrents for 3 or 4 or 5 miles and then disappeared entirely.

Director POWELL. Yes; but I will show you where nearly all those occur. They nearly all occur in this great basin lying around here [indicating by reference to the map]. That is the great region of lost streams. Within this region there is no drop of water that runs to the sea—the region colored green and olive on that map. All of the water is lost.

Senator JONES. Is there much rain-fall in that region?

Director POWELL. It varies from 3 to 16 inches.

Senator PLUMB. Is it carried by subterranean streams?

Director POWELL. No; it is all evaporated.

Senator PLUMB. Then that is not aided by the moisture carried there, but is simply evaporated and falls again?

Director POWELL. It gets a good deal of moisture from the west. Moisture evaporated in this region [indicating] is carried over on to the Rocky Mountains here. The progress of moisture across the continent from west to east is by steps. It is precipitated and evaporated, and again precipitated and again evaporated, and passes across the continent in that manner, by steps, and it is chiefly thrown down on the mountains.

As to the Gila drainage basin—the lower portion of the Gila is a region where the mountains gather the main part of the moisture, and where these waters flow down and are lost in the sand, ultimately to be evaporated; so that the irrigation of the Gila region depends on three things: First, the utilization of the running streams abounding in these mountains and along Salt River, and streams which head in the mountains. Secondly, it depends upon the utilization of the storm waters; less than one-half of the mountains of the region give rise to living streams. The streams of the mountains of the lower land are in the main intermittent streams. When the rains of the spring start the streams start and run out to the valleys until they are lost, and when the dry seasons come all the streams of the mountains dry up and the waters roll down into those lands and can be recovered in various ways, but in the main, in that country, in part by artesian wells and in part by wells that must be pumped.

While on that subject I will say that the pumping of water from wells is a peculiarity of American industry. I never appreciated its magnitude until this past season. This fall I sent Mr. Nettleton to Spain to investigate some questions. He has just returned, and tells me that there is nothing in France, in Italy, or in Spain to correspond with the industry growing up in this country by the use of pumps for the recovery of water. American genius has done this; it has invented

pumps that can be run so cheaply and of such power that it is possible, at an expense of $200 or $300, to irrigate a good farm in any part of the country where good wells are found, by the use of pump-water.

Senator CASEY. The pumps being run by steam?

Director POWELL. By steam one way or another.

Senator CASEY. And it is in this region that they are using those pumps?

Director POWELL. In this region they are beginning to develop the pumping process.

Senator PLUMB. You saw some of those pumps in operation in Colorado this past year, did you?

Director POWELL. Yes.

Senator PLUMB. Did they seem to be successful there?

Director POWELL. Very successful.

Senator PLUMB. Not only on the ground of work but of expense?

Director POWELL. Yes. They have made the expense trivial. A boy or a woman can run such pumps. They are very simple.

Senator JONES. Did they not say they had some pumps in operation to which they sent somebody only once or twice a day to look after them?

Director POWELL. Yes, they sent somebody to feed them once or twice a day.

The genius for invention has solved the problem for the irrigation of a very large district of country in this Southern region, which is of great importance for this reason: that is the region in America of the highest temperature, the region where the date, the palm, and the orange grow, and where cotton and sugar can be cultivated, and all the products of a subtropical climate grown.

The CHAIRMAN. Would not that remark apply to the places east of the Rocky Mountains in Kansas and Nebraska where the waters are lost?

Director POWELL. Yes; but there are few countries where it is lost as it is there. It is lost in the valley of the Arkansas and in the valley of the Platte and in many other places, but there is only a portion lost there, while here it is wholly lost, and the people will have to depend upon the lost water entirely for irrigation or the region will be absolutely desolate.

The CHAIRMAN. They have some irrigation in the Salt River Valley.

Director POWELL. Yes, on the streams above, as I have explained.

Senator REAGAN. The mountain streams all dry up in that place?

Director POWELL. Yes.

Senator REAGAN. But you remember that it was a dry season when we were at Phœnix?

Director POWELL. Yes. I excepted the Salt River and Gila River regions in what I have been saying. All through California and around here [indicating] there are short north and south ranges, which do not rise very high, which furnish no perennial streams. It is in that region of country that they must depend on pump-waters for irrigation, and to some slight extent on artesian waters.

Senator REAGAN. Senator Plumb made an inquiry about the understreams that flow through the sand. If you remember, some witnesses had a good deal to say to us about there being underground rivers in some places.

Director POWELL. Yes. If you wish me to talk on that subject I shall be pleased to explain the matter.

Senator PLUMB. If you have finished with what you wished to say

about the surface waters I shall be glad to ask you some questions about the other.

Director POWELL. I shall be glad to answer any questions.

Senator PLUMB. In your judgment is this under-deposit of water a standing body of water merely, or is it a flowing stream?

Director POWELL. I do not believe it is a flowing stream.

Senator PLUMB. That is to say, is it a great cavity into which those streams flow?

Director POWELL. It is rather a complicated question. I will explain it. There are two problems with regard to it. Where the waters disappear in the sand, as they do here in the Great Basin, they spread out in what is known as a "sink." Where they spread out in the sands along a great river, as in the case of the Arkansas and the Rio Grande, the valleys of which descend 4, 5, 6, 8, or 10 feet to the mile, the waters gradually creep down these valleys with a distinct forward movement.

Senator PLUMB. And are replaced by waters coming behind?

Director POWELL. Yes; but not in the sense that there is a stream or flow of water. The water simply percolates through these sands.

Senator PLUMB. That would be important as affecting the quantity of this water?

Director POWELL. Precisely.

Senator PLUMB. As to whether any of those waters if removed by a ditch would be instantaneously replaced by a pump, what have you to say?

Director POWELL. I am very glad you have brought that question up. But let me go on one moment. When you pass the mountains of Colorado along these streams for the first hundred miles there are perhaps only 10 or 15 inches of rain-fall, while on the mountains there is an excess of rain-fall. The water is gathered on the adjacent mountains and precipitated. But when you get from 100 to 200 miles away from the mountains the attraction of the moisture is not to the mountains, but is again eastward, and again the precipitation is greater; so that at some distance away from the mountains you get a greater rain-fall than you do nearer the mountains. It therefore requires less water for irrigation there than it does above, because nature supplies a greater share. On the other hand, the snows of the valleys are forever supplying a local rain-fall, and the people do not depend on that which comes from the mountains. The increase of local rain-fall to 20 or 22 inches across that country produces rain-water in the valley much faster than it can be pumped out. The quantity of water is ample, but the supply will come from the adjacent country, and not from above, if the water is used in irrigation above. The lands of the valley will be supplied with water by the storms of the plains.

Senator REAGAN. At one place the people described to us an underground river. They said they were putting in tubes farther up and gradually raising them so as to pour the water out on the surface.

Director POWELL. It is a good illustration of one of the "sinks" that I have been describing. Here is a river running down from the mountains—mountains on this side and mountains on that—with springs, etc., all gathering into a valley, which at last debouches into a plain below. Right by Tucson is a sink in which the water disappears. If you go into that valley you will find that in one place it opens out quite wide, while in other places it narrows up into a cañon. Wherever it is narrowed by the solid rock you will get a good flow of water.

Senator PLUMB. A large portion of the water supply of the city of Denver is derived in the same way. But my idea was to inquire whether

that was a deposit of water or a flowing stream. Suppose, for instance, you should take out 50,000 cubic inches of water in a given moment of time, the question is whether this flow of water that is back of it, coming from this hidden source, will immediately replace it?

Director POWELL. Such questions are properly answered by experience, and so what I have to say——

Senator PLUMB. I understand that, but I thought you had made some observations on it.

Director POWELL. I have.

Senator PLUMB. There is no doubt about water being there, and no doubt as to the possibility of getting it out, because the average slope in western Kansas is about 7 feet to the mile, while 2 or 3 feet is sufficient for that purpose.

Director POWELL. My judgment is this, that the supply of water is permanent; that it is permanent by reason of the storm-waters of that region, which are great. Many times in the last twenty-two years I have been over that ground and witnessed storms. When the rains do come the sheet of water that comes down from the adjacent hills is enormous. I am confident the source of water is perennial for that reason, even though the waters of the river should be cut off in Colorado.

Senator PLUMB. That is to say that acts practically as a reservoir for the storm-water?

Director POWELL. Yes; and on the other hand I do not believe that the supply is inexhaustible. I believe there is a limit to it.

Senator CASEY. It might be carried off by constant drainage. You have often seen water where the drainage is constant and where the water, although very full at one time, becomes exhausted.

Director POWELL. As to that section of the Arkansas River that runs through the State of Kansas and has a valley several miles in width, I believe that a large area can be redeemed by irrigation by the use of its underground water, yet I believe it has its limits.

Senator PLUMB. You think that the taking away of the water will have the same effect underground as it has on the surface streams, that is to say, it will dimish the supply below?

Director POWELL. Yes; that is to say you can not irrigate illimitably with it, but it will irrigate perhaps two or three hundred thousand acres.

Adjourned.

SECOND DAY'S SESSION.

WASHINGTON, D. C., *January* 21, 1890.

The committee met pursuant to adjournment. Present, Messrs. Stewart (chairman), Casey, Jones, and Moody.

FURTHER STATEMENT BY DIRECTOR POWELL.

The CHAIRMAN. Major Powell, you may resume your statement.

Director POWELL. Mr. Chairman and gentlemen of the committee, I propose rather briefly to review some facts relating to important drainage basins, and to continue the statement which I was making at the adjournment of the last meeting of the committee, but in the main I shall omit the engineering problems and confine myself more exclusively to the problems of civil administration.

The next basin in order, continuing from the point where I left off at the last meeting, is the drainage basin of the Colorado.

The Colorado is one of the great rivers of the continent, being more than 2,000 miles in length. It runs in the main from north to south and from highlands to lowlands, so that it passes in its course through many climatic zones. It heads in the Wind River Mountains and drains a large region in the Territory of Wyoming. It also drains a portion of Utah and a portion of Colorado. The regions drained in Wyoming are very cold, because they lie at a great altitude. All the lands in Wyoming that can be irrigated by the tributaries of the Colorado or Green River are lands valuable mainly for the cultivation of potatoes, hay, oats, and perhaps rye. In some few of the low places wheat may be cultivated. But I will designate for our purposes at the present time the potato zone of the Colorado.

Following down the Colorado to the lower regions in Utah and some few valleys in the State of Colorado we get into a region where wheat is cultivated, but the areas that can be redeemed along the Grand and Green Rivers for these purposes are not very great. Still farther down the Uintah Valley, in Utah, and the Grand River Valley, in Colorado, corn may be cultivated. There are some minor valleys for the next 700 miles along the Colorado that can be used for the cultivation of corn.

More than four-fifths of the upper drainage basin of the Colorado lies from 5,000 to 8,000 feet above the level of the sea. About the rim of this basin stand the Wasatch and Uintah Mountains on the west, the Wind River Mountains on the north, and the great Rocky Mountain system on the east; all that vast area, as shown in the map before you, is all drained into the Colorado River.

As there are great gorges from 200 and 300 feet to 5,000 feet in depth, in general the streams run so far below the surface of the country that they can not be used for agriculture. But nearer to the mountains, on each side, there are high valleys in the potato region that I have described.

In the regions below the cañons, at the mouth of the Grand Cañon, as it is called, the Colorado falls into a great valley, across which some mountains stand, but in the main it is a low and very warm valley, and a region where rice can be cultivated. And throughout the world the great rice regions in general are where irrigation is practiced. In this valley ultimately rice and the vegetables and fruits of that zone can be cultivated in great abundance. On the lower Colorado there may be cultivated to advantage, also, cotton, sugar, and especially the date palm, because the country is far to the south and low.

Now these are the problems involved in the civil administration: A part of the waters are in Wyoming, a part in Colorado, a part in Utah, a part in Arizona, and a part of California, and they are to be divided between those States and Territories. But there will be no difficulty in dividing them in the upper regions because the land which can be covered is less than the water will serve. So that all the upper region of the Colorado that can be irrigated may be by the streams, and there will arise no necessity for a division of the water between States, counties, districts, and people. But when we come to the lower portion of the Colorado there they will have to be divided. A small portion of Utah, of Nevada, and California on the west, and Arizona on the east can use these waters, and after all the waters have been used above, as I have described, after all the region is irrigated that it is possible to irrigate, there will still be a vast volume of water in the Colorado that can be utilized and divided between the States and Territories that I have mentioned. But at the

present time there are no means by which those waters can be divided between them. It is probable that 5,000,000, 6,000,000, or 7,000,000 acres of land can be irrigated in this lower region. So that ultimately it becomes a problem of great importance to divide these waters.

Passing then from the Colorado drainage, I will omit some of these minor areas and speak of the Sevier drainage.

The Sevier heads in plateaus in southern Utah and runs northward, then turns westward, where it is lost in the desert. The people of Utah have already taken out the waters of the Sevier below the lower part of the valley to irrigate very large areas, and until within two or three years, settlements have been crowded on the head of the Sevier, and the people above are beginning on the upper portion of the Sevier to take out water from its tributaries, and already they have done this to such an extent as to cut off the water from the farms below. So that the problem now is to divide the waters of the Sevier in such a manner as that there will be no conflict. The people above are taking out the waters of the stream on to land which is of comparatively little value for agricultural purposes because it is cold and in the region designated as the "potato region."

The lower valley of the Sevier is warm, and agriculture is practiced there with great success. But, if the process of abstraction of the waters from above continues, as it has been for two or three years past, much of the water of the Sevier will be cut off and the lower settlements destroyed.

Senator CASEY. What are the people above on the Sevier raising?

Director POWELL. Hay, potatoes, oats, etc.

Senator CASEY. Do they raise any wheat?

Ditector POWELL. No; not that I know of. It is possible that there is a small portion where wheat can be raised, but the most valuable lands are in the lower valley.

I will speak next of the Jordan drainage, the Jordan being one of the upper rivers flowing into Salt Lake, and from which the irrigation of a large tract in Utah is had.

Utah Lake cuts in two the valley of the Jordan. Above, the Provo and Spanish Fork, and a number of other small streams flow into Utah Lake. The waters in these upper streams are taken out to irrigate the valleys they pass through. But not all of their waters are used above; a very large amount, in the season when irrigation is not practiced, flows into Utah Lake. Utah Lake is a natural reservoir for the Jordan. Now, irrigation has been carried on and developed in the valley of the Jordan to such an extent that practically the waters of the irrigating season are already utilized. So that, the development or increase of the area of irrigation in the valley of the Jordan, including the whole valley, is to be made by storing the waters, and they can be largely stored in Utah Lake. But if Utah Lake is used as a reservoir, it must be used in part by cutting down the outlet and in part by damming the outlet so that the waters of the winter may be stored therein.

To do this the lands belonging to people above will be flooded. Already there has been conflict there, but the church authorities stepped in and settled the matter. The last time there was conflict, a committee of arbitration was formed, and each of the two counties involved paid one-third of the expenses of the damage, and the church from the tithes paid the other third. They settled the difficulty in that manner. But the difficulty still remains, if any increase is to be made in the area to be irrigated in the valley of the Jordan.

And on Bear River we have another difficulty which is more than an intercounty and intercommunity difficulty. Bear River heads in Wyoming, flows northward into Idaho, makes a great circuit in Idaho, and then returns to Utah, where it ultimately empties into the Great Salt Lake. It is therefore an interstate problem, and the people of Idaho and the people of Utah are now in constant conflict. During the past season the governors of those Territories and their citizens have been petitioning the Secretary of the Interior on the subject. There has been much newspaper warfare about the matter, and meetings and conventions have been held to determine how the waters of the Bear shall be divided. A large portion of the valley of the Bear—the warm and valuable portion of the Bear—lies in Utah. The region drained by the Bear—the valley of the Bear—which lies in the Territory of Idaho is cold. There is a small area of good land, but in the main the lands are grass lands and potato lands, such as I have described. So that, there is now pressing upon the Department, Congress, or some authority, the problem of dividing the waters of the Bear between Wyoming, Idaho, and Utah.

Passing to the west side of the Great Basin, I will say one word in general of the Great Basin.

The streams which head in the Great Basin, or drain it, do not run to the sea. So that there are many small streams, like the Jordan and the Sevier, which head in the mountains standing about the Great Basin and are lost in the sinks and salt lakes, and many of them in the sand. Of the several drainage basins in Nevada I shall not stop to speak now, except a few.

Here another problem arises peculiar to the region itself. The Truckee, the Carson, and other rivers of Nevada, head in the Sierra Nevada Mountains within the State of California. The main waters used in the western half of Nevada have their sources in California. Nearly all the reservoirs for the storage of waters of these streams must be constructed in California. The people, therefore, who live on these rivers and depend on irrigation have their sources of supply in another State.

If they are to increase the area of irrigation from these streams—and it may be very largely increased; we have already made the survey showing that a very large amount of water can be stored in Lake Donner, Independence Lake, Tahoe, etc., in California—if the people are to utilize these waters in irrigation on their lands below, they will have to go into another State to do it—they will have to construct their canals and reservoirs outside of their own State. It makes a very serious interstate problem, therefore.

I shall pass hurriedly over all these points simply to bring out hereafter the interstate problems in the main. Perhaps I had better refer to the Humboldt River.

The Humboldt River heads in low mountains in central Nevada from many small streams and springs. It is largely supplied with storm water, so that during seasons of storm a great flood of water rolls down the Humboldt River. During exceedingly dry seasons it is almost dried up. The problem of the Humboldt is, therefore, to store the storm waters immediately along this basin and to utilize the small streams on which they now depend in dry seasons.

We have here the great valley of California [indicating on the map]. I shall make no mention of the waters of the San Joaquin and its tributaries, but wish to say a few words about the waters of the Sacramento.

The Sacramento Valley is a region in which irrigation is practiced to

some extent, but in which it is not absolutely necessary. During the last two or three years especially the people of that region have come to understand that irrigation would benefit them very greatly, and they are now developing irrigation in that valley. Ultimately they will use a large part of the waters of the Sacramento for that purpose.

There is a double problem involved here. The Sacramento and its tributaries have heretofore been used for hydraulic mining. When the miners and farmers of this region come to understand that it is wise for them to use the waters of the streams for irrigation, the conflict between the farmers and the miners will cease. The works necessary to utilize the Sacramento for irrigation and the works necessary to utilize the waters for hydraulic mining will be common works, and both parties will be interested; so that the problem that has divided the interests of that valley between the miners and farmers can ultimately be settled to the advantage of both.

The CHAIRMAN. I am afraid that is a little overstated. It will never be settled until they get the gold out.

Director POWELL. Perhaps I had better dwell upon that point a little. First, on the American River and all those rivers used for mining purposes they have learned enough to know that the waters can be stored there. If the waters are stored above in the lateral valley to be used in irrigation below in the valley of the Sacramento, an equable stream can be preserved along the Sacramento. A flood stream need never be allowed to run in the valley; the waters can be controlled in such a manner that floods will not spread over the valley.

The CHAIRMAN. I believe that can be done.

Director POWELL. Then the destruction to the land which is sometimes done in two or three weeks of flood-time will not happen.

The CHAIRMAN. The great conflict is that they have a great many storage reservoirs. They can work these mines with these waters by the hydraulic process, but it will not pay to work them by any other. It is estimated that, in the old river beds which run north and south at an elevation of 600 feet above the level of the sea, there are a thousand millions of gold. That is the estimate of experts based on results obtained prior to the injunctions against hydraulic mining. But in working the mines by that process they cover up the land below and that is the controversy.

Director POWELL. The land is covered in this manner: The streams that are used in hydraulic mining tear the hills down and distribute débris over the low lands—the materials of which the hills are composed. The bowlders and gravel of these hills are carried a short distance, finer material much farther, sand a somewhat greater distance, and part of the material, exceedingly fine, is carried very far down the river and there deposited. The rivers, therefore, run like rivers of mud. That débris accumulates along the course of the river, chokes the river, and forms dams and bars from point to point. So that, when the spring rains come and the snows melt the flood comes down all at once, and, the channels of the river being choked, the flood spreads itself over the valleys, and the débris from the channels of the river bury the land many feet. The Senator knows how that is. I have traveled along there for miles when there was a good stage road and telegraph line, and a few years after along that same road the telegraph poles were buried. Here and there one would have its top protruding above the débris.

Senator JONES. How large an area was covered in that way?

Director POWELL. I remember indefinitely the area that I saw covered from 2 and 3 to 30 and 40 feet in depth, but as well as I can remember—it is several years since I was there—it was from 300 to 400 square miles.

The CHAIRMAN. The Bear and the American Rivers when I first saw them had deep banks—40 or 50 or 60 feet deep. The beds of the streams are now above those banks. The highest estimate is that it has covered up 1,000,000 acres of land. Some have put the estimate higher, to 1,500,000 acres of land. But a great deal of that land has become good again by exposure, and it has helped the land that was back from the river by raising the water-bed and moistening that land. So that what was dry land back of the river has become moistened land. But the farms near the river have been all covered up. The miners were enjoined from proceeding with this kind of mining. There is a vast amount of money in these mountains, estimated by the best experts at a thousand millions, and until these injunctions are removed this gold will never be utilized.

Director POWELL. I pass from California directly to the Snake River or Shoshone River, where some important problems exist. The Snake River has its origin in Wyoming, passes into Idaho, crosses the Territory of Idaho, becomes the boundary line between Oregon and Idaho for a long reach, finally passes across the State of Oregon, whence it proceeds north to Washington Territory, and thence turns westward through Washington Territory until it joins the Columbia.

The Snake is a river of great magnitude. Its waters can be stored in part in Wyoming, in part in Idaho. Lakes have already been discovered as sites for reservoirs, by which a large amount of water, 2,000,000, or 3,000,000 acre-feet—that is, water enough to irrigate 2,000,000 or 3,000,000 acres of land—can be stored at very small expense. That is in the upper part of the Snake River Valley.

The waters of the Snake River must be divided between Wyoming, Idaho, Oregon, and Washington, and interstate problems have arisen in part, and will arise hereafter, of great importance; because it contemplates the irrigation of 6,000,000 or 7,000,000 acres of land.

Senator Casey. What products can be produced there?

Director POWELL. It is a wheat and corn region.

Senator CASEY. Throughout its whole length?

Director POWELL. This is a warm valley, a valley in which it is desirable to live on account of its low altitude; but the upper part of Wyoming is high and cold.

In the utilization of the waters of the Snake arise some problems which are found elsewhere, but which can be stated very well here; and perhaps I had better dwell upon them at this point.

If the waters of the Snake should be taken out at points near together by small canals along the river and used on lands near to the river it will be much easier to develop the first, perhaps, 1,000,000 of acres of irrigation along that river. That is to say, it is possible to construct diverting dams and to take the water out of the river by piece-meal along the river here [indicating on the map] for the irrigation of the first 1,000,000 acres of land. If the water should be taken out high up on the river and carried far back over the valley, an area of four, five, six, seven, or eight times as large as I have mentioned—I can not say exactly how much larger until the surveys are completed—can be irrigated by those waters, and if they are taken out in this manner the cost per acre will be much less than if they were taken out by piece-meal.

But further than that, if it should be taken out piece-meal to irrigate 1,000,000 acres of land, then the rights become vested in irrigation works there, and then they can not go above and take the water out, because it will cut the water out from the people below, and they will have to be bought out to increase the area of irrigation. So that it becomes important, if all the waters of the Snake River are to be ultimately used for irrigation, and many million acres of land redeemed which can be redeemed in this manner, to provide now, before little canals are built along its course, that the Snake be taken out higher in a few places in great bodies, or we shall get into the same condition they are in in the valley of the Nile.

It is estimated that the waters of the Nile, which are now irrigating 5,000,000 acres, will serve three times that amount with an annual expenditure less per acre than it now costs to serve the 5,000,000 acres. But if works are to be constructed and the waters of the Nile taken out from the supplies above on the lands where drainage is not so necessary, it can be done only by buying out the interests on the Nile entirely. The English are now working at this problem of how to meet the necessity now existing and drain the lands that are now becoming swamp lands, and make the annual expenditure per acre much less and increase the area to be irrigated. The problem which I stated about the Snake River appears again and again in all the great streams of this country.

The Columbia River heads in British territory. It is a great river and carries a vast volume of water. After it crosses the boundary line between British territory and our own there is a great valley which can be ultimately irrigated, and there is abundant water which can be used. But a large part of the water that is to be used in the United States can be used only by constructing works on British territory; that is to say, a large part of the area which could be irrigated in the United States could not be irrigated without building works on British territory. But, on the other hand, the problem is not so serious. There is more water than the people of the British territory need.

The Kootenay River, one of the important tributaries of the Columbia, in British territory, flows into the United States and returns to British territory, and there arises an international problem; and so it is with a great many of the smaller streams along the border, streams which I need not stop to mention, where international problems are involved.

Passing over to the headwaters of the Missouri River, we find that the Milk River heads on British territory and flows down into the territory of the United States, and with regard to that river international problems are involved. Beside the international problems on the Missouri River we have these interstate problems: That river heads in Montana partly, in Wyoming in fact, and flows through both the Dakotas southward, so that ultimately there is to be devised some means of dividing its waters between Montana, North and South Dakota, and perhaps a part may ultimately be used in Nebraska. The Big Horn and Powder Rivers head in Wyoming and run northward into the Yellowstone, and the waters of each of these rivers have to be divided between Wyoming and Montana.

The Yellowstone itself presents some interstate problems. The chief storage area of the waters of the Yellowstone is in the National Park.

The Yellowstone Lake is a natural storage basin. In it can be stored waters for the irrigation of 300,000 or 400,000 or 500,000 acres of land. Along the Yellowstone River is an important problem worthy of brief mention here. The Yellowstone has its course through Montana in a

deep cañon 400, 500, or 600 feet below the mesa above. Along its course is a valley varying from 2 and 3 to 6 and 7 miles in width. A part of that lower valley is valuable for irrigation; a part is not valuable, and if water were used over the whole of that valley it would be largely wasted. But the mesa lands above are good, and it would be necessary to take the waters of the Yellowstone above this region, high up, and spread them over the mesa lands on each side. The Cheyenne and Niobrara Rivers involve problems between Wyoming, the Dakotas, and Nebraska. The waters are to be divided between those sections, and the people are in conflict. Some very interesting letters have passed between the governors of those localities protesting against the use of these waters, and Congress has been appealed to.

Senator CASEY. Between Wyoming and Nebraska?

Director POWELL. Colorado and Nebraska, and likewise between the governors of Colorado and Kansas. Then below, along the Cimarron and Red Rivers, we have interstate problems.

I think I have dwelt long enough on this point; but I wanted to bring out the fact that something must be devised by the United States to solve these interstate problems which are imminent—some common scheme for dividing the waters between these States and Territories.

The CHAIRMAN. Before leaving that point I wish to ask a question. You spoke of the Missouri and Yellowstone. Have sufficient explorations of the Missouri been made to determine whether that river can be taken out or not?

Director POWELL. A very large part of the Missouri River can be used in Montana, a part in North Dakota, and another part in South Dakota. It can be used alike in Montana, North Dakota, and South Dakota. I will only mention here the major streams.

Captain DUTTON. The Missouri River can not be taken out below the Great Falls for a distance of 300 or 400 miles.

The CHAIRMAN. It will have to be taken out above the falls?

Director POWELL. It will have to be taken out above. The Yellowstone, like the Snake River, is a great river, and the ultimate utilization of these waters is to depend upon great canals.

Senator CASEY. Can the Missouri be taken out above the falls?

Director POWELL. It can be taken out between Bismarck and Helena.

Senator CASEY. That is the Yellowstone?

Director POWELL. No; the Missouri.

The CHAIRMAN. The Missouri has three forks there.

Senator CASEY. Can it be taken out just above the Great Falls.

Director POWELL. That is one of the questions to be examined this summer.

I will very briefly call attention to another problem—the great plain extending from British territory to Mexican territory. There is a region of four or five degrees in width, on a part of which irrigation is absolutely necessary, and on a part of which irrigation is conditionally necessary; that is to say, some years they need irrigation, while in other years the land can be cultivated without irrigation.

The CHAIRMAN. And always beneficially?

Director POWELL. And always beneficially. I have a map exhibiting the artesian wells of the arid lands, extending somewhat over the arid area and the plain east of the well-defined arid lands. This map needs a little explanation so that you may understand it.

Artesian wells have been found in great numbers. The geological basins in which these wells are found and known are colored in the main, as this [indicating on the map]. We have here a basin with many artesian wells in it [indicating].

We have another here [indicating]—the Colorado Basin, the Denver Basin, one in southern Colorado, one in southern Arizona, and one in southern California; another basin there [indicating], and those basins, the geology of which is pretty well known, are in Utah. You see them here [indicating on the map]. In addition to this the people have gone out of the basins geologically known and have experimented elsewhere. Among all those experiments are failures which do not appear on the map; but the successful wells appear and are represented by the dots you observe here [indicating on the map]. A dozen or fifteen wells have been found in that locality. Each dot does not necessarily represent a single well, but sometimes a small group of wells. In some places a single well is found and is represented by a dot. (See map.)

The CHAIRMAN. What is that group of wells there?

Director POWELL. That is in Texas, a part in the arid region and a part in the subhumid region.

Senator JONES. Are they flowing wells?

Director POWELL. Yes. I have not put in the non-flowing wells. There are a great many wells used for irrigation which do not flow over the surface, but the waters rise near the surface and are taken out by pumps. They do not appear on this map, however. The region of country of which I speak, stretching through there [indicating], is one of great interest because of the attempts which have been made to settle the country without resorting to irrigation. During the past fifteen or twenty years in many places other attempts have been made to settle the region. But the settlers who have gone in there have in the main left, settled and left, settled again and left, and so on from year to year. The region of country is on that border land which will be forever attempting cultivation without irrigation. But two, three, or four wet years will occur in succession, when agriculture will be quite successful; then will come two or three bad years and they will be disastrous and the people will migrate. Now, however, the people are appreciating the benefits of irrigation, and when they come to realize that irrigation is necessary for permanent success and prosperity the difficulties will disappear. But while the water supply is not sufficient to irrigate all that country, it is sufficient to irrigate large areas.

Now, I speak first of these artesian waters not because they are of the most importance or of greater magnitude, but because the people are looking in that direction more than any other.

The regions of country underlaid by artesian waters are not at all known from a geological stand-point—we can not say to what extent they are so underlaid. But there is sufficient evidence to lead one to believe that artesian waters are somewhat abundant.

A geological survey is necessary in order that the geological basins may be mapped, and then experimentations in the areas thus mapped will confine the work to regions where there is prospect of water, and by experiments in part and by geological examinations in part, it will be possible to determine what artesian waters are found in that region. When they are found they will be valuable for domestic and horticultural purposes. And though the cost of boring wells is large, and the cost of redeeming lands will be comparatively great, greater than the utilization of flowing rivers, yet the great value given the land by irrigation will warrant the expense.

Artesian reservoirs can never furnish waters for agriculture on a scale of sufficient magnitude to be considered as an important source of supply. The amount of waters which porous rocks will supply is always very insignificant compared with the amount necessary for

irrigating any great tract of land. More than half the agriculture of the world is dependent on irrigation. Of this, a very insignificant amount depends on artesian wells. There are wells here and there in Europe, Asia, Africa, and America, and in some of the great islands, but altogether they furnish a very small amount of water for agriculture. If all the artesian wells used for irrigation in the world were assembled in Dakota, they would not irrigate a county of land. But there are other serious reasons why the attention of the people of the great plains should not be directed too confidently to this resource. It is the experience with artesian wells everywhere throughout the world that if too many are bored in any basin all are destroyed thereby. In the northern Illinois district, it was hoped that the great city of Chicago could be supplied with water for domestic purposes by artesian wells, but experimentation has proved that, while a few good wells could be secured, a great number was impossible; that the supply of water would be absolutely inadequate for the wants of the city; and so the authorities were compelled to resort to the lake for their supply. Now, to irrigate the site of the city of Chicago would take more water than to supply it for domestic purposes; so that the artesian wells of that district would be entirely inadequate to irrigate an area as large as the city, or perhaps one-fifth or even one-tenth of the area. Some years ago it was pointed out that the city of Denver and the region round about was the site of an artesian basin. The first well site proved to be very valuable, and the desire to secure water for domestic purposes therefrom led to their multiplication. More than three hundred have now been bored, and gradually with the progress of the boring the collapse of the wells has resulted, and now all the wells have to be pumped; there is little or no flowing water from them. These instances might be multiplied all over the world, and the experience of mankind testifies that it would be unwise to encourage the people of any district of country to depend upon artesian waters for irrigation on any large scale for farming. Waters for domestic purposes, for irrigating gardens, and for supplying stock ranches may thus be obtained in many regions, and the supply of water that can thus be furnished is of value; but when considered as a source for agriculture, for the cultivation of fields and large tracts of country, it will always be inadequate; and it is unwise to encourage any people to engage in agriculture on a large scale and depend on irrigation from artesian wells.

For the district of which I am now speaking, extending from the British to the Mexican line in a broad belt across the plains on both sides of the hundredth meridian, the people will ultimately be compelled to depend upon another source of supply, and one so important that in comparison therewith the artesian supply sinks into insignificance and seems hardly to be worthy the mention. I refer to the use of the storm waters. One-third of the agriculture carried on by irrigation throughout the world is prosecuted by the storage and use of storm waters, and the experience of mankind in this respect is replete with lessons that can not be neglected. The region to which this is especially applicable is the sub-humid region. It differs from what I have called the arid region in that it generally has a greater rain-fall, distributed more evenly over the country, as it is not interrupted by great mountains where the precipitation is concentrated, having from 15 to 22 inches of rain-fall in the average year; sometimes more, sometimes less. There are many years when agriculture is prosperous without

irrigation; there are others when it fails without an artificial supply of water. Gradually with the progress of agricultural development it is possible to cover the country with storage basins, or tanks as they are usually termed, in which water may be held to be used in seasons of drought. By this means the farmers may be able to tide over the dry years, and farming may be made prosperous and highly remunerative thereby from year to year. It is in this direction that the attention of the people of that region should be turned.

There is another source of water for that country of far greater importance than that of artesian fountains, but far less than that of the storm waters. I refer to sand reservoirs along the channels of the streams, especially of the great rivers. In that region of country the stream valleys are often great beds of sand, into which sinks the water which comes from the distant mountains, and into which sink the storm waters that come from the adjacent hills. Experience in other countries shows that this source of supply is worthy of consideration, and the experiments now in progress in the Arkansas Valley give indications of like character.

Mr. Chairman, I have prepared a statement in relation to the artesian wells of the Great Plains which is partly in tabular form, with a brief explanation of the geologic conditions under which these artesian formations exist. With your permission I will present it.

GEOLOGICAL DATA RELATING TO ARTESIAN WELLS IN THE SUB-HUMID REGION OF THE GREAT PLAINS.

THE DAKOTAS.

Location.—The artesian wells in the Dakotas are situated east of the one hundred and first meridian, and, with the exception of the one at Pierre, they are east of the one hundredth meridian. They occur in great numbers in the Red River Valley, making a belt through the Dakotas, with adjacent portions of Minnesota and Manitoba, and making a second nearly parallel belt running from Yankton northward to Devil's Lake.

Classification and reference to geological horizons.—The successful wells thus far bored in the Dakotas and adjacent regions, may be arranged in four groups, with reference to the geological horizons from which they derive their water supply. These are, (1) wells of little depth which do not pass through the drift; numerous in the Red River Valley; (2) those which penetrate to the Cambrian rocks, as at Grafton, N. Dak.; (3) those deriving their water supply from the middle or upper portion of the Cretaceous, illustrated by a single well in the western part of Cass County, and by several wells in the Red River Valley which pass through the drift; (4) those penetrating to the Dakota sandstone, the basal member of the Cretaceous. This group is important, and is illustrated by numerous wells ranging from Vermillion and Yankton northward to Devil's Lake.

Wells in the region adjacent to the Dakotas.—Artesian wells have been bored in the States and Territories bordering the Dakotas on the east, north, and west, a knowledge of which is valuable in discussing the possibilities of the subterranean water supply in those States themselves. The favorable conditions for supplying water in the Red River Valley extend northward into Canada, as far, at least, as Winnipeg, and eastward into Minnesota.

The successful wells in Manitoba, with the exception of one at Rosenfeld, about 20 miles northwest from Emerson and St. Vincent, are all in superficial deposits. The well forming the exception has a depth of 1,037 feet, and penetrates to the Cambrian. The water flowing from it is saline.

The shallow wells of Manitoba are as follows:

Location.	Depth.	Strata penetrated.	Water supply.
	Feet.		
Near Letellier	250	Drift (150 feet!) and Cretaceous or Silurian.	Saline and alkaline.
12 Manitoba Wells of Morris.	250	do.	Do.
Dominion City	107	Drift till under lacustrine and alluvial beds.	Brackish.
Near Niverville (about twenty wells).	40–170	Drift, nearly all till	Good, fresh water.
Winnipeg (several wells)	50–100	do.	Do.

The successful wells of eastern Minnesota which penetrate strata below the drift are as follows:

Location.	Depth.	Strata penetrated.	Water supply.
	Feet.		
Houston County:			
Brownsville	590	Cambrian	
Wabasha County:			
Lake City	820	do.	
Goodhue County:			
Red Wing	450	do.	
Dakota County:			
Hastings	1,160	do.	
Mendota	857	do.	Fresh, rising 10 feet above surface.
Freeborn County:			
Albert Lea	300	Devonian	
Blue Earth County:			
Minnecpa Falls	1,000	Cambrian	
Nicollet County:			
Saint Peter	200	do.	
Hennepin County:			
Minneapolis	205	Lower Silurian and Cambrian, *i. e.*, Trenton and St. Peter sandstone.	Fresh, abundant.
St Louis County:			
Tower	400	Archean schists	Do.
Traverse County:			
Brown's Valley	465	Cretaceous (Fort Benton shale), to Dakota sandstone.	Saline and alkaline.
Kittson County:			
Humboldt	644	Cambrian	Do.

The unsuccessful wells of eastern Minnesota are as follows:

Location.	Depth.	Strata penetrated.	Water supply.
	Feet.		
Mankato	2,204	Cambrian	Rose to 90 feet below surface.
Minneapolis	622	Trenton and Cambrian	
Do	1,431	do	
Do	2,150	do	
St. Paul	671	do	
Do	850	do	
Freeborn	950	Devonian	
Stillwater	3,500	Through Potsdam into Keweenewan.	
Duluth	1,507	Archean	
Tracy	724	Through Cretaceous to granite	
Moorhead	1,425	Drift, 220; Cretaceous, 150; Archean, 1,055.	

The wells of Minnesota which are successful but do not penetrate below the drift are as follows:

Location.	Depth.	Strata penetrated.	Water supply.
Blue Earth and Faribault Counties:	*Feet.*		
Sterling, Mapleton, Wells, etc. (about two hundred wells in the vicinity of Maple River, on the area of the Glacial Lake Minnesota).	25–120	Till, with included seams of water-bearing sand and gravel.	Fresh, copious.
Douglas County:			
Osakis	60	do	Fresh, scanty.
Hudson	35	Glacial drift (till) with included seams of water-bearing sand and gravel.	Do.
The following are in the Red River Valley, on the area of the Glacial Lake Agassiz:			
Traverse County:			
Near Wheaton	119–182	do	Fresh, abundant.
Tintah	55	do	Do.
Do	45	do	Do.
Do	67	do	Do.
Near Tintah	35–160	do	Do.
Wilkin County:			
Champion Township, many wells.	50–66	do	Fresh, very copious.
Atherton	11	do	Fresh.
Do	37	do	Do.
Do	45	do	Do.
Clay County:			
Near Barnesville	35	All these go through thin lacustrine and alluvial beds, then are for most of their depth glacial drift (till), with seams of water-bearing sand and gravel.	All fresh, with copious supply.
Near Sabin	180		
Near Moorhead	100–228		
Kragnes	155		
Near Georgetown	180		
Becker County:			
Hamden	75		
Do	110		
Norman County:			
Perley	200		
Halstead	250		
Eight miles northeast of Halstead	165		
Do	219		
Ada	217		
Lockhart	140		
Lockhart vicinity	125–150		
From Ada to Crookston many wells	100–200		
Polk County:			
Near Kittson	80–112		
Do	140		
Carman	190		
Near Crookston	180		
Do	190	Alluvium and lacustrine beds, then glacial drift (till), in which are water-bearing seams of sand and gravel	Fresh, copious.
Do	205	do	Do.
Do	236	do	Do.
Vicinity of Crookston, probably one hundred wells.	165–240	do	Do.
Fisher	285	do	Alkaline and saline, copious.
Near Angus	45	do	
Do	70	do	
South Angus	253	do	Do.
Marshall County:			
Argyle	150	do	Do.
Do	285	do	Do.
Tamarack and vicinity.	74	do	Do.
Do	95	do	Do.
Do	218	do	Do.
Stephen	220	do	Do.
Do	240	do	Do.
Kittson County:			
Donaldson	45	do	Do.
Near Kennedy	95	do	Do.
Near Hallock	119	do	Fresh, copious.
Near Northcote	30	do	Do.
S. Vincent	165	do	Saline, copious.

West of the Dakotas wells have been bored in search of artesian water at the following localities:

Location.	Depth.	Strata penetrating.	Water supply.
	Feet.		
Glendive		Laramie or Fox Hills	
Miles City (fourteen wells)	180–550	Laramie (?)	
Billings	1,000		Not flowing.
Bozeman			
Helena	160	River gravels	200 gallons per minute.

Wells in the Dakotas.—The deep wells of the Dakotas, with exceptions noted later, are situated in a belt ranging from Vermillion and Yankton northward to Devil's Lake, and derive their water from the Dakota sandstone. The available data concerning these is given in the following table:

Locality.	Depth.	No. of wells.	Diameter of bore.	Temperature.	Pressure (per square inch).	Elevation (surface above sea).	Surface of Dakota (above sea).
	Feet.		*Inches.*	°*Fah.*	*Pounds.*	*Feet.*	*Feet.*
Vermillion	350					1,150	
Yankton	610	15	6	62	32	1,196	616
Do	165				140	1,196	
Yankton vicinity		15				1,196	
Tyndall	600				122	1,418	
Mitchell	1,300					1,301	
Plankinton	1,500				140	1,528	
Kimball	1,100				95	1,788	
Chamberlain						1,363	
Letcher	600					1,300	
Woonsocket	1,300				250	1,308	
Artesian City						1,313	
Vilas						1,420	
Huron	863		6	60	170	1,285	422
Brookings	900					1,636	
Miller	1,148		5	80	125	1,587	438
Highmore	1,552		6	68	25	1,890	338
Harold	1,300				80	1,801	
Hitchcock	965		3½–4½		186–218	1,139	
Redfield						1,300	
Frankfort						1,296	
Faulkton	1,200					1,595	
Gettysburgh	1,300					2,082	
Ashton	915		6	55	50	1,296	381
Andover	1,070		4½	64	90	1,476	406
Groton	960		5		187	1,301	341
Aberdeen	908	Many.	5 3/16	60	140–160	1,300	396
Columbia	965		4⅝	60	176	1,304	339
Ipswich	1,270		6	65	70	1,530	260–300
Ellendale	1,087		4–5–6	65	125	1,453	366
Jamestown	1,476	2	6	70	95	1,400	50
Jamestown vicinity	1,321						
Devil's Lake	1,511		3½			1,470	39

Locality.	Artesian head (above sea.)	Water supply (per minute).	Can be irrigated by direct flow, allowing 4 inches for 3 miles.	Character of water.
	Feet.	*Galls.*	*Acres.*	
Vermillion		80	95	
Yankton	1,270	3,000	3,570	Slightly hard, drinkable, used in boilers.
Letcher		Large.		
Vilas				In process.
Huron	1,678	1,400	1,666	
Brookings		None		Said to end in granite. Minnesota Geological Survey thinks this doubtful.
Miller	1,876	1,000	1,190	Excellent; good for all purposes.
Highmore	1,948	14	16.6	Soft and of good quality.
Pierre				In process.
Hitchcock				Used for irrigation.

Locality.	Artesian head (above sea).	Water supply (per minute).	Can be irrigated by direct flow, allowing 4 inches for 3 miles.	Character of water.
Faulkton			71	Abandoned; drilling another.
Ashton	1,411	60		
Andover	1,684	300	357	
Groton	1,733			
Aberdeen	1,670	3,500	4,165	
Columbia	1,708	4,000	4,760	Soft.
Ipswich	1,692			Soft (slightly brackish).
Ellendale	1,742	600	714	Soft; not pleasant to the taste.
Jamestown	1,690	375	446	Analysis given on page 11.
Jamestown vicinity				Abandoned.
Devil's Lake	1,575	40	47	

One hundred gallons per minute will give 4 inches of water to 119.3 acres in three months.

The wells enumerated above derive their water from the Dakota sandstone. Those at Vermillion and Yankton were begun in the Fort Benton. The remainder were begun in the Fort Pierre and pass through the Fort Benton.

Chemical composition.—The water in the wells indicated in the above table is generally brackish or alkaline, not therefore adapted for drinking or culinary purposes, and objectionable for use in steam boilers on account of the mineral salts deposited from it.

The water in the artesian well at Jamestown has been analyzed with the following result:

[Hardness, 21 degrees.]

	Parts per million.	Grains in U. S. gallon.
Test for organic matter:		
Free ammonia	2.4	
Albuminoid ammonia	.046	
Permanganate test:		
Oxygen consumed by carbonaceous oxygenic matter in three hours	6.7	
Nitrates	None.	
Nitrates	Trace.	
Silica	35.7	
Alumina	3.5	2.0823
Carbonate of iron	2.2	.2041
Carbonate of lime	188.0	.1283
Sulphate of lime	249.0	10.6743
Sulphate of magnesia	154.2	14.5241
Sulphate of soda	1139.4	8.9944
Sulphate of potash	81.5	66.3602
Chloride of sodium	369.1	4.7523
Phosphates	Trace	21.5296
	2222.6	129.2496

Professor Dodge, the chemist who made the analysis, states that in his opinion this water would not be suitable for regular use as a drinking water.

A qualitative analysis of the water in the well at Devil's Lake has also been made by Professor Dodge, which shows that it is of about the same composition as the water in the Jamestown well.

The following notes from report of Irrigation Committee, Vol. I, 1883, in reference to the water from other wells of the same class as those just mentioned, is here inserted:

Yankton.—Water slightly hard; pleasant to the taste; is used in boilers and gives good satisfaction.

Highmore.—Water very soft and of good quality.

Miller.—Water excellent and good for all purposes.
Ipswich.—Water very soft; contains soda, potassium and allied salts; tastes slightly brackish.
Columbia.—Water contains mineral properties; very soft.
Ellendale.—Water not pleasant to the taste; very soft.

These analyses and notes indicate that the water derived from the Dakota sandstone does not contain sufficient alkaline salts to be injurious to vegetation, especially in a region that has a rain-fall as great as that of the eastern part of the Dakotas.

In various portions of the testimony before the Irrigation Commission, the beneficial effects of irrigation with the water of Dakota sandstone wells are mentioned.

The temperature of the water derived from these wells in general increases with the depth of the boring. This is shown in the following table:

Well.	Depth.	Temperature.	Well.	Depth.	Temperature.
	Feet.	°*Fah.*		*Feet.*	°*Fah.*
Highmore	1,890	68	Columbia	1,304	60
Miller	1,587	80	Aberdeen	1,300	60
Ipswich	1,530	65	Ashton	1,296	55
Andover	1,476	64	Huron	1,285	60
Ellendale	1,453	65	Yankton	1,196	62
Jamestown	1,400	70			

Pleistocene wells.—The wells which do not penetrate below the drift are situated in the Red River Valley, principally in the bed of Lake Agassiz. The formation a few miles back from the river is glacial till, nearer the river the till is overlain by lacustral salt. Fresh water is obtained from the wells south of Blanchford, N. Dak., and Crookston, Minn. Farther north their waters are almost invariably brackish and alkaline, and not suitable for household use or drinking, although they are liked by cattle and horses, and are not injurious for this purpose.

The wells in the Red River Valley number more than one thousand. Of these about one-half are in North Dakota. They range in temperature from 46° to 50° Fah. in the south, to 42° Fah. at the north. The available data concerning a few of those in North Dakota is here inserted:

Location.	Depth.	Strata penetrated.	Water supply.
	Feet.		
Richland County:			
Farmington	93	Thin alluvial and lacustrine beds; then the principal thickness consists of glacial drift (till), in which are water-bearing seams of sand and gravel.	Fresh, copious.
Dwight, vicinity (ten wells)	85–110		
Colfax	85		
Do	125		
Do	128		
Do	135		
Walcott	110		
Do	120		
Walcott, vicinity	104		
Do	131		
Do	227		
Cass County:			
Durbin	160		
Everest	160		
Argusville	157		
Do	158		
Argusville, vicinity	130		
Do	153		
Gardner	125		
Gardner, vicinity, (many wells)	96–200		

Location.	Depth.	Strata penetrated.	Water supply.
Cass County—Continued.	*Feet.*		
Grandin (within an area of 50 rods).	105 158 187 248		
Traill County:			
Quincy	213		
Kelso	109		
Do	110		
Kelso, vicinity	110		
Do	175		
Blanchard (ten wells)	175–404	Partly in cretaceous	Brackish, copious.
Hillsboro	105		
Do	125		
Do	175		
Do	198		
Grand Forks County:			
Grand Forks	265		
Do	270		
Manvel	166		
Do	175	Thin alluvial and lacustrine beds; below these a great thickness of glacial drift (till), in which are water-bearing seams of sand and gravel.	All in this northern part of the valley are brackish and alkaline.
Walsh County:			
Ardoch	164		
Minto	196		
Do	200		
Grafton	156		
Auburn	175		
Pembina County:			
St. Thomas	175		
Glasston	200		
Hamilton	179		
Bathgate	143		
Bathgate, vicinity (eleven wells)	130–160		
Neche, vicinity	220		

The wells not included in the classes already noted are as follows:

Location.	Depth.	Strata penetrated.	Water supply per minute.
	Feet.		*Gallons.*
Grafton	915	Passed through stratified rocks to granite.	1,000.
Tower City	670	Fort Pierre shales to Niobrara horizon.	9½; rises 33 feet.
Casselton and vicinity	317–350	Passed through the drift into cretaceous rocks.	Brackish alkaline, copious.
Amenia and vicinity	250–279	....do	Do.
Blanchard and vicinity (six wells)	300	....do	Do.
Mayville	395	....do	Do.

All of the wells enumerated in the last table, excepting the one at Tower City, are situated in the Red River Valley, and passing through the glacial drift enter older formations.

The one at Grafton passes through the Cambrian and into the granites beneath. Water was first reached at the depth of 503 feet; 400 feet deeper and resting on granite, a second sandstone stratum was reached which contained saline water. The well was continued 12 feet into the granite, but was subsequently filled so as to receive water only from the first water-bearing strata reached.

The remainder of the wells in the Red River Valley which pass through the drift are supposed to derive their supply from the middle portion of the Cretaceous.

Sources of water supply.—The source of the water in the wells which do not pass through the drift, although indefinite and perhaps impossible to determine accurately, owing to the irregular stratification of the deposit, is certainly not distant, and depends on the rain-fall and

topographic configuration of the immediate region. It is possible, however, that the salt wells in this region may be supplied from springs in older rocks which are deeply drift-covered. The principles applicable to continuous water-bearing strata included between impervious beds and conducting water from distant sources, can not be applied to wells of this class.

The wells which derive their supply from the Fort Pierre, Fort Benton, Dakota, and Cambrian formations, on the other hand, penetrate evenly bedded strata, and depend for their supply on the hydrostatic pressure of water derived from distant sources.

In order to determine the source of the water in these wells, one must ascertain where the water-bearing strata out-crop at an elevation sufficient to insure a flow at the surface where the wells are situated.

The Cambrian and Silurian rocks underlying the eastern portion of the Dakotas come to the surface in Minnesota and adjacent portions of Canada. It is barely possible, as I have been informed by C. R. Van Hise, that these strata may derive their water from the eastern outcrops indicated. A general western inclination of these rocks from their outcrops west and north of Lake Superior seems probable from what is known concerning them, but the data in hand are not sufficient to warrant positive conclusions.

The eastern outcrop of the Cretaceous system coincides in North Dakota with the eastern escarpments of the Coteau des Prairies along the western border of the Red River Valley. Its western outcrop is along the eastern bases of the various front ranges of the Rocky Mountains and about the Black Hills.

The elevation of the region in which the wells penetrate the Dakota sandstone in the eastern part of the Dakotas is from 1,000 to 1,900 feet above the sea. The water comes to the surface under a pressure of from 15 to 187 pounds per square inch. The maximum is at Groton, the altitude of which is 1,300 feet above the sea. The pressure in this well is sufficient to raise the water 432 feet, and even if the loss of pressure by friction is not considered it is evident that the source of the supply must have an altitude of at least 1,700 feet above the sea. The pressure in other wells in the same series indicates a source of supply at an elevation of 1,950 feet. It is known from railroad surveys and other sources that there is no land to the south, east, or north of Groton at a sufficient elevation to furnish water under the pressure given, even if the water-bearing strata outcrop at the surface under the most favorable conditions. The eastern outcrop of the Dakota sandstone in South Dakota and the adjacent portion of Nebraska has a maximum elevation of about 1,500 feet. It seems evident, therefore, that we must look to the west for the fountain-head of the wells which reach the Dakota sandstone. The nearest outcrop of that formation at the west is about the Black Hills at an elevation of approximately 3,300 feet above the sea. It comes to the surface again still farther west, about the eastern base of Big Horn Mountains, at an elevation of about 4,500 feet.

The general inclination of the Dakota sandstone and of the strata which rest upon it is known to be eastward from the eastern base of the Rocky Mountains, although a secondary structure producing anticlinals probably exists. From what is known of the succession of strata in the eastern and western outcrop of the Cretaceous, and from the suggestion furnished by the high pressure of the water derived from the lower member of the series in eastern Dakota, it seems exceedingly probable that the Dakota sandstone forms a continuous stratum beneath the Great Plains. If the water obtained from this stratum is derived from the Rocky Mountain region as indicated by our present knowledge,

it follows that success might be expected if wells were bored in the region between the Red River Valley and the eastern basin of the Rocky Mountains.

The thickness of the Dakota sandstone as given by F. V. Hayden at its outcrop about the Black Hills is 400 feet. At Lincoln, Nebr., as stated by Professor Hicks, it is 204 feet. Along its outcrops it is a porous sandstone sometimes passing into a conglomerate, and where it has been penetrated by borings in the Dakotas it is very friable and open in structure. Its thickness, porosity, and extent, as well as its attitude, so far as is known are all in favor of its being an abundant source of artesian water.

Thickness of strata above the Dakota sandstone.—The formations which occur in the general region under discussion, as given by F. V. Hayden, are as follows:

Name.	Character of strata.	Thickness.
		Feet.
Loup River beds	Fine loose sand, with some layers of limestone	300–400
White River group	White and light drab clays, with some cavities of sandstone and local layers of limestone.	1,000
Wind River deposits	Exposed principally in Nebraska	1,500–2,000
"Fort Union," Laramie	Sandstone with shale	2,000–10,000
Fox Hill	Gray ferruginous and yellow sandstone and arenaceous clays.	500
Fort Pierre	Dark gray plastic clays above; dark beds of very fine unctuous clay, containing much carbonaceous matter with veins and seams of gypsum, etc., below.	700
Niobrara	Lead gray calcareous marls above; light yellowish and whitish limestones below.	200
Fort Benton	Dark gray laminated clays, sometimes alternating near the upper part with layers of light gray limestone.	800
Dakota	Yellowish, reddish, and occasionally white sandstone, with alternations of various colored clays and beds of lignite.	400

The surface throughout the region occupied by the Dakotas has been greatly eroded and it is not probable that the entire series as given above anywhere exists. It is to be expected also that the strata above the Dakota sandstone may be found of variable thickness and lithological character. These considerations as well as the secondary structure of the Great Plains would have to be investigated in order to predict for any locality at what depth the water-boring strata might be reached. Some of the wells in eastern Dakota derive their water supply from middle Cretaceous. The conditions to the west of where these wells are located seem equally favorable for obtaining flowing water from this horizon. It is to be expected, however, that water derived from these strata would be less pure than from the Dakota sandstone and consequently of doubtful value for irrigation. The Laramie may also be expected to yield artesian water.

Beneath the Dakota along the western outcrops there are shales and other impervious strata belonging to the Triassic system. It is to be expected that these coarse Triassic beds will carry water, but the great depth at which they occur underneath the Great Plains probably renders their consideration as a source of water supply necessary; besides, the Triassic strata are so highly charged with easily soluble salts that water derived from them would be too alkaline and saline for irrigation or domestic use.

NEBRASKA.

The geological formations of this State comprise the Upper Coal Measures, and possible Permian; the Cretaceous, but including only the Dakota, Fort Benton, Niobrara, and Fort Pierre, and the White River Tertiary of Hayden.

Lithological composition.—The component beds of the Coal Measures are shales, limestones, and sandstones, in alternating bands; the limestones of greater or less thickness form a prominent feature of the outcrops along the Missouri and in the numerous railroad and water cuts leading to this river.

The Cretaceous formations present the following composition: The Dakota, from 300 to 400 feet of a soft, loose textured, white sandstone, separated by narrow beds of shale into bands of from 50 to 80 feet; its width of outcrop in Nebraska is about 60 miles. The Fort Benton, a series of dark black or bluish gray, compact, argillaceous, shales, with a few narrow limestone bands; in thickness between 300 and 800 feet, but probably nearer the former figure in Nebraska. The Niobrara, between 200 and 400 feet in thickness, composed of shales and limestones, the latter a most prominent feature of the formation, and in Dakota, Nebraska, and Kansas of a decidedly chalky nature rather than that of a massive, hard limestone, as along the foot-hills of the Rocky Mountains. The Fort Pierre, essentially a formation of light-gray, plastic, clay shales, of variable thickness in Nebraska, owing to its deposition in undulations of the Niobrara below, and to erosion from its summit prior to the laying down of the White River Tertiary above.

The White River Tertiary is a formation of sandstones, conglomerates, and interbedded shales. It is the surface formation of western Nebraska and southwestern Dakota, where it rarely shows a thickness of over 400 or 500 feet.

Areal distribution.—The areal lines of division between the Tertiary, Cretaceous, and Carboniferous ages are clearly defined. That between the Cretaceous and Coal Measures, which also constitute the eastern limit of the Dakota formation in Nebraska, crosses the Missouri River a short distance below Dakota City, follows down the west side of the river a few miles inward from its bluffs to a point on the Platte about 8 miles above its mouth, when it inclines to the southwestward, passes through Cass, Otoe, Johnson, and Gage Counties, and joins the eastern boundary assigned the formation in Marshall County, Kans. The line of division between the Cretaceous and Tertiary crosses the northern boundary of the State in longitude 100, the southern in 99, and within these limits has a broad convexity to the east, crossing the Platte a little to the east of the ninety-eighth meridian; with the exception of a small area of erosion on the upper Republican, in which the Pierre shales are exposed, the entire State west of this line is occupied superficially by the White River Miocene.

Non-conformities exist both above and below the Cretaceous, the Dakota resting in uneven line upon the Coal Measures or Permian, the White River upon the greatly eroded surface of the Pierre; furthermore, here as elsewhere there also exists abundant evidence of a prominent break in the continuity of deposition between the Niobrara and Fort Pierre formations, within the Cretaceous itself.

Geological structure.—The geological structure of Nebraska is that of gently inclined strata, having a general dip to the eastward somewhat less than the slope of the surface, with a slight "basining up" of the formations in the eastern part of the State, the dip there being to the northwest in continuation of that of the corresponding beds in Dakota and Kansas.

The following altitudes in Nebraska, which are of use in connection with the geological structure, are from Aughey's "Physical Geography and Geology of Nebraska" and Gannett's "Dictionary of Altitudes in the United States."

Locality.	Altitude.	Remarks.
	Feet.	
Scott's Bluffs, on State line	6,051	Northern line of State.
Niobrara River, southeast of Fort Robinson	4,118	
Indian Creek, northwest corner of State	4,013	
Fort Robinson, 103° 30′ meridian	3,781	
Mouth of Snake River, one hundred and first meridian	2,690	
Mouth of Keya Paha, ninety-ninth meridian	1,960	
Niobrara, ninety-eighth meridian	1,240	
Pine Bluffs, one hundred and fourth meridian	5,061	In the southern half of State.
Sidney, one hundred and third meridian	4,095	
Ogallala, one hundred and second meridian	3,216	
Kearney, ninety-ninth meridian	2,157	
Average of five, on ninety-seventh meridian	1,203	Northern to southern boundary.

Central City, the lowest point on the eastern line of the Tertiary, has an altitude of 1,708 feet. The eastern boundary of the Cretaceous will lie between 1,000 and 1,200 feet, a fall of at least 3,000 feet from the western line of the State.

Artesian wells.—Nebraska has apparently been but slightly explored with reference to the possibility of artesian wells. Record has been found of but four, one at St. Helena, a short distance below Yankton; one at Omaha; one at Lincoln, a mineral water; and one at Brownville, in Nemaha County, in the southeastern part of the State.

That at St. Helena derives its waters from the Dakota sandstones, at a depth of 400 feet, and in reality belongs to the system of South Dakota. The flow is copious.

The wells at Omaha, 750 feet, Lincoln, 985, and Brownville, 1,001 feet, derive their water from various strata in the Coal Measures. Of these the well at Omaha affords pure, fresh water. The Lincoln well yielded fresh water (not artesian) at a depth of 100 feet; a strong brine at 244 feet, the base of the Dakota, and medicinal water at 544 feet. The last is the water used. The flow is strong. Of the Brownville well no record of its water can be found.

From the above facts it is observed that the great water-bearing formation of the eastern part of the prairie region has been tapped at but one advantageous point in Nebraska, at St. Helena. Although the geological structure of Nebraska does not afford the confining beds of granite, quartzite, etc., to the easterm rim of the Dakota formation as it does in the Dakotas, nevertheless it is reasonable to presume from the success attending boring in the State of Kansas to the south, where the conditions are approximately the same as in Nebraska, that water may be obtained at numerous points over this belt; furthermore it is not impossible that the Tertiary beds themselves may afford flows at advantageous points within the area covered by them.

Tabular statement relating to the artesian wells of Nebraska.

Geological horizon.	Location.	Depth.	Delivery.	Remarks
		Feet.		
Dakota	St. Helena, Cedar County	466	Copious	Pure.
	Omaha, Douglas County	750	Good	Do.
Carboniferous	Lincoln, Lancaster County	985	Copious	(1) Brine from 244′ (Dakota), cased off. Mineral from 544′ Carboniferous.
	Brownville, Nemaha County	1,001		(2) No other data
	Beatrice, Gage County	1,200		(3) No flow.

KANSAS.

The geological formations included within the area of Kansas comprise the Subcarboniferous, the Coal Measures, the Upper Carboniferous and Permian, the Trias, the Cretaceous, including, however, only the Dakota, Fort Benton, and Niobrara, and a Tertiary formation, probably Miocene.

Lithological composition.—The Subcarboniferous is recognized in the well-known Subcarboniferous limestone, and occurs only in the very southeastern corner of the State.

The Coal Measures, Upper Carboniferous, and Permian are an alternation of sandstones, limestones, and shales. In the Coal Measures the shales are often locally developed to great thickness; the limestones are very persistent, and the sandstones are rather subordinate. In the higher formations the sandstones become more prominent. The thickness of the Coal Measures is at least 1,000 feet, while the Permian and Upper Carboniferous comprise about 2,000 feet.

The Triassic shales, limestones, and "Red Beds" (shales with narrow sandstone bands), of a variable thickness up to 300 feet, succeed the Permian and Carboniferous rocks. It is probable that this formation is wanting in the northern portion of the State towards the Nebraska line.

The Dakota formation, as in Nebraska, is largely composed of sandstone, but with a somewhat greater development of shales; it varies in thickness between 300 and 500 feet.

The Fort Benton ranges in thickness from 50 to 260 feet—a wide variation—and in its component beds departs a little from the normal composition further north. According to Professor Mudge its upper 60 feet is a bed of limestone, in layers from 1 to 3 feet thick, underlain by 60 feet of bluish-black shale abounding in concretions of a calcareous nature, this series underlain in turn by 140 feet more of shales, somewhat variable in composition and with several narrow bands of limestone distributed through them.

The Niobrara is of nearly its usual character, but is rather more chalky in appearance. Its thickness in Kansas varies from 75 to 200 feet.

The maximum thickness of the Cretaceous in Kansas is estimated by Professor Mudge to be about 900 feet. The basal member, the Dakota, rests unconformably upon the Carboniferous below.

The Tertiary of Kansas consists of cemented coarse-grits and sandstones. Its age is regarded by Robert Hay as Miocene. It is everywhere unconformable with the Cretaceous.

Areal distribution.—The areas covered by the several formations of Kansas are: for the Trias, Permian, and Carboniferous the southeastern third of the State; for the Cretaceous, a broad median belt lying in a northeast-southwest direction; for the Tertiary, the northwestern fifth of the State, together with a small extension from Colorado into its southwestern corner.

The line of division between the Cretaceous (Dakota) and the formations below starts at the Nebraska line, in Marshall County, follows a somewhat irregular line through Washington, Clay, Dickinson, Morris, Marion, McPherson, Rice, Reno, Pratt, Comanche, and Clarke Counties, where it crosses the southern boundary of the State. Its western boundary, or the line between it and the Tertiary, starts in Jewell or Phillips Counties, and passes with irregular trend west-southwestward, leaving the western boundary of the State a short distance north of the Arkansas River.

Of the Cretaceous formations the Dakota occupies a belt along the eastern border of about 50 miles' width, the remainder being occupied by the Fort Benton and Niobrara, but largely by the latter.

The geological structure.—Although both the Carboniferous beds and the eastern half of the Cretaceous exposures have a gentle dip to the westward, there is nevertheless a general rise of the beds to the westward, especially well brought out in the Cretaceous series itself by the exposure of its several members along the western border of the State. This rise, so far as the Cretaceous is concerned, amounts, according to O. St. John, to from 1,100 to 1,700 feet, the altitude of its exposures in Hamilton County being in the vicinity of 3,150. There is, therefore, as in Nebraska, a general eastward fall of the water-bearing beds, with a in slight though pronounced "basining up" to the eastward, with the axis in the region of Larned, extending northeast and southwest.

Artesian wells.—The artesian wells of Kansas derive their waters from four different formations: The Miocene, Dakota, Trias, and Carboniferous. Of these the Miocene wells—with two possible exceptions in Norton and Sheridan Counties in the northwestern part of the State—are at present confined to Meade County on its southern boundary; the Trias wells occur, one at Richfield in Morton County, and one at Larned in Pawnee; the Carboniferous, one at Russell, Russell County, and one at Winfield, Cowley County, while the remaining or Dakota wells are distributed over the Cretaceous belt from near the Nebraska line to that of the Indian Territory.

The Miocene wells of southwestern Kansas have their source in the Miocene grits and sandstones already mentioned as present in this portion of the State. These coarse, arenaceous, and pebbly beds are covered by a soft, bluish, putty-like clay or gumbo, which forms the subsoil of the region, is thoroughly impervious, and is the effective confining stratum for the waters beneath. The gravelly beds receive their waters at their outcrops in the very western part of the State and in Colorado into which they extend. The wells number about sixty or seventy and vary in depth from 50 to 185 feet. A number of them flow from 18 to 36 gallons per minute, and a still greater number flow only from 1 to 6 gallons. None of them are strong wells, though the water of some of the lower ones will rise from 15 to 20 feet above the surface. Concerning the wells in Norton and Sheridan Counties nothing of detail is known.

The wells of the Trias, at Richfield and Larned, derive their waters respectively from depths of 570 and 750 feet. The Richfield well yields 6.3 gallons per minute, but is somewhat mineralized. The Larned well flows over 250 gallons per minute, and rises as a fountain between 10 and 15 feet. Its waters are a strong brine with medicinal properties.

Of the Carboniferous wells, that at Russell is 977 feet deep, the one at Winfield 1,200 feet; both have good flows, but are strongly saline.

The Cretaceous wells of Hamilton County are the only ones of which detailed data exist. They are numerous, range from 200 to 300 feet in depth, and flow from 45 to 100 gallons per minute. Some of them are used for irrigation purposes. The well at Great Bend is 1,400 feet deep, but receives its waters, which are saline, from the Dakota sandstone at a depth of 344 feet. It has a strong flow, which rises 30 feet above the surface.

From the geological structure of Kansas and the results of borings in other States it is quite possible that the Coal Measures may be found productive of artesian waters whenever attempts with this special object in view shall be made.

Tabular statement relating to the artesian wells of Kansas.

No.	Geological horizon.	Location.	Depth.	Caliber.	Delivery per minute.	Remarks.
			Feet.	*In.*	*Galls.*	
1	Tertiary.....	Edward's well, Meade Co.	155	....	36.00	Pure.
2	....do	.....do	165	....	32.4	Do.
3	....do	.....do	185	....	29.6	Do.
4	....do	Mart's well, Meade Co....	140	....	66.6	Do.
5	....do	Bower's well, Meade Co ..	125	....	37.3	Pure; waters rise 15–20 feet above surface. Temperature Meade Co. wells 60° F.
6	....do	Norman's well, Meade Co.	127	....	37.3	
7	....do	Cox well, Meade County..	175	....	9	Pure.
8	....do	.....do	142	....	9	Do.
9–68	... do	60 other wells, Meade Co..	50–175	....	1–30	Do.
69	Tertiary ?.....	Norton, Norton County...	.....	....	.....	No data; may be Dakota; depends on depth.
70	....do	Hoxie, Sheridan County..	.....	...	.....	
71	Dakota	Smith Centre, Smith Co ..	.....	...	.....	No data; may be Tertiary; depends on depth.
72	....do	Great Spirit Spring, Mitchell County.	.....	...	.....	Natural artesian flow.
73	....do	Miltonvale, Cloud County.	.....	....	.....	No data as to water.
74	....do	Wa Keeney, Trego Co....	.....	....	.....	Do.
75	....do	Hays City, Ellis County..	.....	....	.....	Do.
76	....do	Great Bend, Barton Co ...	344	....	6.75	Saline; well bored to 1,400 feet, but water from 344 feet; rises 30 feet above surface.
77	....do	Kinsley, Edwards County.	.....	....	.....	No data as to water.
78	....do	Dodge City, Ford County .	.....	...	.....	Do.
79	....do	Santa Fé, Haskell County.	.....	....	.....	Do.
80	....do	Ulysses, Grant County ...	.....	....	.....	Do.
81	....do	Opera House, Coolidge, Hamilton County.	239	....	45	Pure; water rises 15–20 feet above surface; now choked owing to opera-house fire. Temperature 61° F.
82	....do	Peck's well, Coolidge, Hamilton County.	298	6	100	Pure and medicinal; water rises 15–20 feet above surface; medicinal properties slight. Temperature 61° F.
83	....do	Border's well, near Coolidge, Hamilton County.	200	....	8	Pure; water rises 15–20 feet above surface; used for irrigation. Temperature 61° F.
84	....do	Burt's well, near Coolidge, Hamilton County.	275	....	35	Do.
85	....do	Nolan's well, near Coolidge, Hamilton County.	240	....	53	Do.
86	....do	Rich's well, near Coolidge, Hamilton County.	240	....	50	Do.
87	....do	Syracuse, Hamilton Co ...	1,000	....	.....	Water rose only to 90 feet below surface.
88	....do	Ashland, Clark County...	.....	....	.....	No data as to water.
89	Triassic	Richfield, Morton County.	600	....	6.3	Pure and medicinal; mineralization slight. Temperature 66° F. Dakota furnished no flow; penetrated Trias 265 feet; water from 570 feet.
90	....do	Larned, Pawnee County..	750	....	250	Saline and medicinal; water spouts 10–15 feet high Temperature 65° F.
91	Carboniferous ..	Russell, Russell County ..	977	....	Good..	Saline; may be Triassic.
92	....do	Winfield, Cowley County.	1,200	....	..do ...	Saline; rises 6 feet above surface.

TEXAS.

The geological formations of Texas involved in the areas of artesian wells include the Coal Measures, the Cretaceous, and the Tertiary.

Lithological composition.—The Coal Measures consist principally of limestone, sandstone, millstone-grit, and shale. The limestones and sandstones exist in about equal proportions and constitute the chief part of the formation. The sandstone is both massive and thin bedded, is fine grained or course, passes into grit, or conglomerate, and exhibits

every degree of hardness. It is interbedded with shales in successive strata reaching 100 feet in thickness.

The Cretaceous of Texas differs considerably from that at the north. According to Shumard it consists of an upper and lower member. The former consists of limestone and sandstone, in southern Texas the limestone predominating, but being largely replaced by sandstone in northern Texas, the limestone here occurring in thin bands separating the heavier beds of sandstones.

The Lower Cretaceous is composed chiefly of marly clays with some limestone, sandstone, and gypsum. The clays and sandstones occur in alternating beds of variable thickness. The sandstone is fine-grained to coarse, thinly laminated, is often calcareous, and usually quite soft.

Both Upper and Lower Cretaceous vary greatly in thickness, the former reaching a maximum of 1,000 feet on the San Pedro River, the latter 2,500 on the upper Red River.

The Tertiary formation to be considered in this connection occurs as a bed of soft, white sandstone 200 feet thick, known as the Carrizo sandstone. It rests unconformably on the Cretaceous, as does the Cretaceous upon the Coal Measures.

Areal distribution.—The Coal Measures, not less than 2,000 feet thick, are confined to the northern half of the State. They are overlaid by a narrow belt of Permian on their west, the area of the two being inclosed on the east, south, and west sides by the various strata of the Cretaceous, chiefly those of the lower division. The western boundary of the Permo-Carboniferous formation passes through Baylor, Throckmorton, Jones, Taylor, Runnells, Concho, and Menard Counties, the eastern through Montague, Palo, Pinto, and Lampasas Counties.

The Cretaceous series as a whole is of wide extent, the portion west of the Carboniferous area reaching far beyond the western boundary of the State into New Mexico. The prevailing dip of the Cretaceous and Carboniferous formations from near the eastern edge of the latter westward is to the northwest; east of this point it is to the eastward.

The extent of the Carrizo sandstone is at present unknown. Its western boundary has been traced for a distance of about 100 miles, from near the town of Uvalde, southward to the Rio Grande River. Its dip is to the southeastward.

Artesian wells.—The artesian wells of Texas derive their waters from the sandstones of the Coal Measures, from those of the Cretaceous, and from the Carrizo sandstone of the Tertiary.

Of the depth or flow of the wells within the limit of the Coal Measures nothing is at present known, but it is probably somewhat variable from the very nature of their component strata.

Of the depth or flow of the greater number of the Cretaceous wells likewise nothing is known. In the southern part of the State, however, existing data enable the following statement:

The wells of San Antonio, two in number, 225 feet and 450 feet in depth, probably both derive their waters from the lower portion of the Cretaceous, though it is possible the deeper one, to the east of the city, may find its supply in the Coal Measures. The former of the two wells affords an excellent drinking water and has a steady, though not strong, flow; the latter has also a steady flow, stronger than that of the shallower well, and its waters, although used for ordinary drinking purposes, have medicinal properties that may render them of special value in the future.

The Cotulla well, 1,008 feet deep, is also probably of lower Cretaceous origin, though it may extend a short distance into the Carboniferous; its waters have a strong flow and are of superior medicinal properties

In the northern portion of the State, the wells of Fort Worth and Dallas derive their waters from the basal sandstones of the Cretaceous, at a depth of 350 and 750 feet, respectively. The dip is to the eastward. In this section the upper confining stratum is apparently the limestones of the chalk formation (Niobrara?).

The Tertiary well at Carrizo Springs penetrates the Carrizo sandstone to a depth of 175 feet, and has an excellent flow of fresh water four inches in diameter.

Tabular statement relating to the artesian wells of Texas.

No.	Geological horizon.	Location.	Depth.	Caliber.	Delivery.	Remarks.
			Feet.	*In.*		
1	Tertiary	Carrizo Springs, Dimmit County.	175	4	Good	Pure.
2	Lower Cretaceous (probably Dakota).	Cotulla, La Salle County	1,008		do	Medicinal; jets above surface 6 ft.; water alkaline-saline. Temperature 86° Fah.
3	do	San Antonio, Bexar Co	225		do	Pure.
4	do	San Antonio (near), Bexar County.	450		do	Pure and medicinal; could be used for medicinal purposes.
5	do	Dallas, Dallas County	750		do	Pure.
6	do	Fort Worth, Tarrant Co	350		do	Do.
7	do	Weatherford, Parker Co				No data as to water.
8	do	Canadian, Hemphill Co				
9	do	Tascosa, Oldham County				
10	do	Armstrong, Armstrong Co.				
11	do	Mobeetie, Wheeler County				
12	do	Clarendon, Donley County				
13	do	Childress County				
14	do	Cottle County				
15	do	Floyd County				
16	do	Margaret, Hardman Co				
17	do	Crosby County				
18	do	Pepper's Ranch, Kent Co				
19	do	Haskell, Haskell County				
20	do	Anson, Jones County				
21	do	Roby, Fisher County				
22	do	Snyder, Scurry County				
23	do	Dawson County				
24	do	Trent, Taylor County				
25	do	Sweetwater, Nolan County				
26	do	Colorado, Mitchell County				
27	do	Big Springs, Howard Co				
28	do	Marienfeld, Martin Co				
29	do	Midland, Midland County				
30	do	Glasscock County				
31	do	Coke County				
32	do	San Angelo, Tom Green County.				
33	do	Centralia, Tom Green Co				
34	do	Aroya, Ward County				
35	do	Toyah, Reeves County				
36	do	Wild Horse, El Paso Co				
37	Carboniferous	Wichita Falls, Wichita County.				
38	do	Archer, Archer County				
39	do	Henrietta, Clay County				
40	do	Montague, Montague Co				
41	do	Throckmorton, Throckmorton County.				
42	do	Jacksborough, Jack Co				
43	do	Palo Pinto, Palo Pinto Co				
44	do	do				
45	do	Albany, Shackleford Co				
46	do	Abilene, Taylor County				
47	do	Tebo, Taylor County				
48	do	Baird, Callahan County				
49	do	Eastland, Eastland Co				
50	do	Eastland County				
51	do	do				
52	do	Stephenville, Erath Co				
53	do	Comanche, Comanche Co				
54	do	Coleman, Coleman Co				
55	do	do				
56	do	Runnells, Runnells Co				
57	do	San Saba, San Saba Co				

In the hasty review which has thus been made of the various drainage basins of the arid region, I have pointed out that there are a number of international questions involved in the use of the rivers for irrigation. One of these questions you have already had presented to you, namely, that of the Rio Grande Del Norte, where the rights of the people of the Republic of Mexico as well as the rights of the people of Texas are threatened and almost destroyed by the people of Colorado and New Mexico. Already claim has been made for more than $1,000,000 by the people of the lower country to re-imburse them for their lost values, or to restore to them by some means the volume of water necessary to carry on their long-established industries of agriculture. Ultimately the problem on the Colorado will be of far greater magnitude. The Colorado itself can be used in our territory, or in Mexican territory, and can be made to irrigate in one or the other country, or in both, many millions of acres. Above, it is in the United States; below, it is in Mexico. Who shall divide the waters between the two nations? On our northern boundary line similar questions are asked. The Columbia and some of its tributaries, some of the tributaries of the Missouri, and others of the Saskatchewan running northward, cross the boundary line, so that their waters must be divided between the two nations. Altogether the problem of the utilization of the rivers for irrigation in the western half of the United States presents international questions, that must ultimately be settled, far exceeding in importance and in values those that relate to fisheries, or any other international subject affecting the industries of the country. In some localities the questions press for solution now; in others they will arise in the immediate future, and must be solved if peace is maintained.

The international problems sink into insignificance in comparison with the interstate problems. Every great river and every great tributary of the entire arid region and of the subhumid region, or more than one-half of the area of the United States, exclusive of Alaska, runs through two or more States and Territories. In a few cases they are boundary lines, in others they head in one political division and run through another. In all these cases the waters must be divided on some equitable and wise principle. In general the headwater States and Territories have it in their power to control the situation. They can take the water and laugh at the rights of the people lower down the rivers. The North Platte is to be divided between Wyoming and Nebraska; the South Platte between Colorado and Nebraska; the Arkansas between Colorado and Kansas; the Canadian River between New Mexico and the Indian Territory; the Pecos between New Mexico and Texas; the Rio Grande del Norte between Colorado, New Mexico, Texas, and the Republic of Mexico; the Colorado between Wyoming, Utah, Colorado, Arizona, Nevada, and California.

All the principal rivers of Nevada head in California. The Bear River is to be divided between Wyoming, Idaho, and Utah; the Snake is to be divided between Wyoming, Idaho, Oregon, and Washington; the Columbia is to be divided between Montana, British America, and Washington; the Missouri and its tributaries are to be divided between Montana, North Dakota, South Dakota, and perhaps Nebraska. In this enumeration I have only taken up the more important streams and have omitted many minor ones that involve severally great interests. Many of these in single cases will involve values of one to five millions of dollars. It is safe to say that the distribution of industries between the States through a division of the waters to be used in irrigation involves industries now established or to be developed of not less than

$1,000,000,000. These problems are already pending in many places to the extent of many millions of dollars and they must all be solved in the immediate future if peace is to be maintained.

The history of interstate feuds in the United States relating to the boundary lines and fishing interests in dividing waters is replete with lessons showing that even such small interests kindle animosities and create difficulties of serious importance. Shall State arm against State over disputed questions relating to the use of water? Will it not be an act of wisdom to settle these disputes in their incipiency before the passions of the people are inflamed and before rights and interests are established. If neglected it will result in the establishment of agricultural industries in various regions that must inevitably be destroyed.

The development of these industries, the growth of vast interests, is now in progress, and the people in many districts are already piling up claims against the Government of the United States which will ultimately amount to vast sums; and if it shall continue for twenty years more as it has progressed for the past five years, claims against the Government will be pressed involving many hundreds of millions of dollars; and if such claims are rejected, hundreds of thousands of people will have their industries destroyed, and will be left in abject poverty to abandon their homes and fields and to migrate to new regions.

Again, if the development of the country is to go on in the present method without regulation and without prevision, agriculture will largely be driven to the mountains, about the sources of the great rivers which ought to be used in the valleys below. If, on the other hand, the right to take out the waters above is overthrown, through the courts and through legislation, and the right to the flow of the stream at the lowest points in the valley where irrigation is necessary is established, the waste of water will be enormous, and not one-fifth, and perhaps not one-tenth, of the possible area of agriculture will be realized. For the ultimate prosperity of the agriculture of those lands, and for the avoidance of conflict, it is necessary that the waters of the entire arid region be divided and relegated by drainage districts to the best lands, in such a manner that the people of each district will know what lands can ultimately be irrigated and what waters can ultimately be utilized; and it is possible by some simple measures of prevision to anticipate nearly all of the difficulties which I have pointed out, in so brief and imperfect a manner, and have them all solved in advance of dense settlement. I have already alluded to the improvident and obstructive rights which are being established along the course of many streams—rights which must ultimately be extinguished, and some of which are now in process of extinguishment. A proper administration of this trust, this heritage of wealth and homes for the people, may be devised. Millions of wealth of this nature may be created which must necessarily be extinguished in the near future. Is it wise to permit its creation?

There is still one other very important class of facts which must be mentioned. The reservoir and canal sites should remain in public possession, in trust for the people who will need them. The statutes already provide for their discovery, segregation, and reservation, but some provision must be made for their utilization. It is manifestly not the purpose to reserve them from use, but to reserve them for use, and to prevent them from falling into the hands of individuals or corporations for speculative purposes. But to whom shall they be turned over for use, and under what conditions shall their utilization be permitted, is the problem yet to be solved.

Equally important with the reservoir and canal sites are the sites for diverting dams along the courses of the streams. It is often the case, and perhaps generally the case, that the waters of a stream may be taken out at a particular place, and the entire volume controlled thereby, and the owner of such a site would have the command of all the agriculture dependent upon that stream. All reservoir sites and canal sites and diverting dam sites should be the property of the agriculturists and not of water companies. The waters themselves should be the property of the farmers and not of companies. If the water for agriculture is to be supplied by companies organized under national statutes or other charters they should be organized only as common carriers of water. It should be established that the land which is irrigated appropriates the waters, and that they are not appropriated by canals, but the water belongs to the farmer and not to the water company. And I believe still further that in the interest of peace and prosperity the farmers should not only own the waters and lands but they should also own the irrigating works.

Such are some of the more important institutional problems relating to the arid lands. The conditions of agriculture in the western half of the United States are unlike the conditions prevailing in the eastern half of the United States, and unlike the conditions of western Europe, from which our people came. The new conditions demand new institutions.

I have reviewed somewhat at length in the two examinations which you have given me the principal problems involved in the arid lands. But I have presumed, and I wish to present it modestly, to formulate in the shape of a bill the ideas which I wanted to present, thinking I could do it in a more systematic and concise manner in that way. I think that this bill, if adopted or enacted into a law, would inaugurate a system that would solve the particular problems which I have indicated. Already some of the members of the committee have heard me talk on this subject. But I will give you an outline of the bill:

First, it is incumbent upon the Government of the United States to, and it is necessary that it should, divide the waters among the different States and Territories, from the fact that in twenty or thirty cases the problems are interstate problems, and in some of these cases the problems have arisen and the people are now in conflict. This conflict, too, is bitter. In other cases they involve only different districts within the same State or Territory. The theory of this bill is that the waters ought to be divided by the General Government.

Senator MOODY. Upon what principle of constitutional power do you attribute the authority of Congress to make these regulations and divide the water?

Director POWELL. I provide for it in my theory, not on a principle of law but on a principle of policy, and the last section of the bill provides that certain sections of the bill shall have no force nor effect until the State or Territory involved accepts it.

Senator MOODY. Congress would have the right to legislate for the Territories in those particulars undoubtedly. But the query was, what authority would Congress have to legislate upon such a subject for the States. Of course, if you take that theory, that the State will have to accept, that ends the matter.

Director POWELL. I have adopted that theory to meet that point.

I have also shown to the committee that all of the lands can not be irrigated, and that it is necessary to select the best.

I have presented to the committee a brief outline of the timber lands of the arid region, and have shown how the timber lands are being devastated by fire. There is before Congress a number of bills providing for a forestry organization by the General Government to protect these forests.

There is still another interest in these arid lands that I may mention before reading the provisions of the tentative bill.

In the area of the arid lands there are vast regions valuable only for pasturage. But if all the rivers, all the creeks, all the brooks and the springs, and all the artesian waters, and all the storm waters are utilized that we hope may be utilized in that country, there will still remain two classes of lands which will not be irrigated for agriculture. There will be large areas valuable for pasturage and valuable for the growth of timber. The timber lands are unfit for agricultural purposes. Waters, in the main, can be found there, but they are so high that agriculture is not profitable. Where timber grows frosts may be expected any month of the year. This tentative bill includes all the interests of that country—the pasture land and timber land, and provides a way for the use of that timber land and the use of that pasturage by the people, and provides further that only the irrigable lands shall be disposed of by the General Government.

If you will pardon me, I will read the bill through, first without comment, and then take up the various divisions and explain their purport and purposes.

(The proposed bill was then read to the committee.)

Director POWELL. Mr. Chairman, the theory of the bill is that there are natural hydrographic basins or drainage areas; that the people of each of these districts should be organized into bodies corporate and politic and constitute commonwealths for the regulation of irrigation, the division of waters, the protection of forests, and the protection of the pasturage lands, and for the utilization of all of these values.

The CHAIRMAN. How would you manage where there are vested rights and you want to get grants to give the districts power to institute proceedings for condemnation; where you want water rights; where you want to take out a ditch to cover land, and where you would have a conflict of water rights?

Director POWELL. I have concluded that that would be a matter for State regulation and not for the United States, and the bill provides that the States must enact the necessary laws. With the knowledge already at hand it is possible to outline most of the natural basins which are described as irrigation districts in this tentative bill. I place before you a map of the arid region outlining such natural districts. It also exhibits the county lines and the State lines, and shows how such districts would be relegated to counties and to States. Most of the districts embrace portions of two or more counties. The county lines, like the State lines, are artificial. In the main they follow parallels and meridians, as do the State lines, and hence usually do not coincide with the natural district lines. A number of districts embrace lands in two or more States or Territories.

The CHAIRMAN. How do you manage to give a district jurisdiction when it is partly in two States?

Director POWELL. I propose that the people of a district embraced in two States organize under United States laws and under State laws which are specified in the bill after the States and Territories have provided for such action, and by the consent and authority of the interested States and Territories.

Section 1 of the bill provides for the survey and designation of the irrigation districts, and three classes of districts are provided. They may be called head-water districts, river-trunk districts, and lost-river districts.

Section 2 provides that the irrigation survey shall select the irrigable lands, and to be governed in the process by the following rules: First, the conditions necessary to secure the greatest area of irrigable land; second, the conditions necessary to secure the most valuable lands for agricultural purposes by reason of climate; third, the conditions necessary to secure the most valuable agricultural lands as determined by soil and subsoil; fourth, the conditions necessary to secure lands that can be irrigated and cultivated with the greatest economy.

Section 3 provides that all lands heretofore irrigated in the arid region or for which irrigating works have been constructed, and all lands selected for irrigation by the Survey, shall be considered as irrigable lands.

Section 4 provides that the United States Survey shall designate the trunk sections of rivers and large creeks, and determine and locate the places on such trunk sections where dams may be constructed, and the routes to be followed in the construction of canals from such trunk sections, and that all shall be done in such a manner as to protect the water rights of the several districts and to prevent the construction of improvident and obstructive works of irrigation, and that it shall be unlawful to construct improvident and obstructive works.

Section 5 divides the waters among the irrigation districts, so that the people of each district will know definitely what waters they are entitled to.

Section 6 provides that whenever a source of water supply and the necessary irrigation works in any district lie within the boundaries of another State or Territory than that where the lands irrigated are situate, the people of the district shall have the right to construct and maintain their works in the State where they are situate, and that it shall be unlawful to levy any tax on or establish any obstruction to the use of such waters, sites, or works by the State or Territory in which they are situate.

Section 7 provides that the irrigable lands may be homesteaded in tracts of 80 acres. It re-affirms the laws relating to mining lands, coal lands, and town-site lands, and provides that all other lands shall remain in the possession of the General Government, to be used by them as catchment areas for the waters of irrigation, for the forests which they grow, and for the pasturage which they furnish, and that the sites of reservoirs and other irrigating works shall remain the property of the General Government, to be used by the people in their corporate capacity.

Section 8 affirms the right of every man who owns an acre of land to his portion of the waters set apart for the irrigable lands of his district.

Section 9 makes it unlawful for any person or corporation to construct irrigating works except in conformity with the statutes of the State or Territory and of the United States.

Section 10 provides a general form of organization for irrigation districts.

Section 11 relegates to the commissioners of each district the authority and duty to provide laws and rules for the use of the waters of the district in irrigation and for other purposes, for the protection and use of the timber and fire-wood of the district, and for the protection and use of the pasturage of the district.

Section 12 provides that such irrigation districts shall be organized under State or Territorial laws, and further provides four methods by which irrigation works may be constructed: First, by co-operative labor; second, by taxes levied on the lands irrigated; third, by the issuance of irrigation-district bonds; and fourth, by contract with companies. But when constructed by the last method, the irrigating works shall after a term of years become the property of the district. It also provides that the State or Territory may enact general laws for the protection and use of forests, and for the protection and use of pasturage.

Section 13 provides for State supervision of irrigation.

Section 14 provides that cities and towns may be excluded from the irrigation districts, and that the waters used for domestic purposes may be designated by State statutes.

Section 15, which is the last, provides for the general consent of the States and Territories involved.

It will thus be seen that the proposition is to organize irrigation districts with natural boundaries, and to relegate to each district the great body of the problems which are involved in this new industry of agriculture; and it divides the waters between the districts in a simple and effective manner. It also proposes that the irrigable lands shall be selected in the interest of all the people, that the greatest amount of agriculture may be carried on; and it provides for the protection and use of the forest and pasturage lands by the people who are interested therein. The vast increase in the value of lands by irrigation makes them an object of speculation. We are starting in a speculation in the West which I believe if unregulated by law, as it now is, with rights to waters undetermined, as they now are, will result in disaster to the farmers and the investors alike; and it will further result in this: that the water and the lands will go into the hands of a few persons, namely, the promoters of irrigating schemes. Be that as it may, the problem of fixing water rights somewhere, so that the farmer and the investor alike may be secure, remains, and is one of the serious problems that must be met; and I propose in the plan which I have presented that the Government of the United States interfere in the matter to the least possible extent; that it divide the waters—not to the farmers—but between districts and States, and then, under guarded provisions, turn over the whole subject to the States and districts and allow them to work out the matter to their satisfaction.

The committee here adjourned, to meet on Friday morning, the 24th inst., at 10 o'clock.

THIRD DAY'S SESSION.

WASHINGTON, D. C., *January* 24, 1890.

The committee met.

Present: Mr. Stewart, chairman; Mr. Plumb, Mr. Casey, Mr. Moody, Mr. Reagan, and Mr. Jones, of Arkansas.

STATEMENT OF DIRECTOR POWELL—Continued.

Mr. chairman and gentlemen of the committee, the work of the Irrigation Survey is naturally divided into three parts and organized into three branches, for there are three classes of work which are best accomplished by three classes of specialists. These are designated as topographic, hydrographic, and engineering branches. Topography is

the basis of the work, and on it the hydrography and engineering depend. This will plainly appear when I come to describe those branches.

Topographic work is map-making. On the passage of the act of October 2, 1888, parties were immediately put in the field and work has been continued up to the present time, chiefly in the field, but to some slight extent in the office. The maps have not all been constructed, but are in part in manuscript. None of them have yet been engraved. The sheets of the map, or the several maps in detail, are constructed with grade curves, or contours, having a vertical interval of 25 feet in the valley and over the more level grounds.

Every 25 feet of elevation above the level of the sea is determined over the entire surface, and the lines on the map represent every 25 feet of change, so in passing from upper to lower heights you have a descent of 25 feet from curve to curve or line to line, as shown on the map. In the foot-hills the lines are 50 feet apart in altitude, and in the mountains they are 100 feet, and yet in any steep regions they are 200 feet apart; so they vary from 25 feet to 50 feet, 100 feet and 200 feet, depending on the nature of the declivities. Such contour maps are very easily understood and express the chief or important facts of natural topography in the simplest manner. It is thus that valley, hill, and mountain, with all necessary detail of relief, are expressed to the eyes in definite quantity. The map shows that the summit of the slope is distant from the foot of the slope say a quarter of a mile, and that the summit is 25 feet above the foot. In this manner the altitude above the level of the sea of every portion of the country is represented, and the whole form is presented at a glance. With a little experience a map of this character is read as easily as a page of print—more so; it is in fact interpreted as a picture. Such are the maps we are making, and I wish to show where they have been made under the two appropriations for the Irrigation Survey.

With the appropriations that have been made it has not been possible to prosecute work in each of the States and Territories of the region and we were compelled to make a selection of districts. In doing so it was thought best to inaugurate work in the most densely peopled regions and where the scarcity of water was most keenly felt. For this reason the Arkansas Valley in Colorado, portions of the Rio Grande in New Mexico, the Truckee and Carson in California and Nevada, the Snake or Shoshone River in Idaho, and other important districts were chosen. I place before you a map of the arid region upon which are colored the districts which have been surveyed up to the present time, and will go on to describe them in detail, commencing on the Arkansas River in the State of Colorado. All of this district as shown on the map, extending from the headwaters of the river in the high mountains of central Colorado nearly down to the Kansas line, and embracing the entire drainage, has been surveyed. We have had two seasons of work in this valley. The first season commenced in October, when there were only a few weeks of good weather left. Still we pushed the work through the winter. In the main the parties beginning in October, 1888, did not return to the office until this fall. It chanced to be a warm and dry winter in the country and we pushed the work through the cold season. The area surveyed in Colorado in 1888 was 13,000 square miles; the area surveyed the present summer was 9,900 square miles; making altogether 22,900 square miles. The area surveyed in Colorado on the Arkansas embraced all the drainage of the Arkansas nearly (but not quite) to the Colorado-Kansas line. You will see by the map to which I now point that there is but a small part yet remaining.

Other parties were put in the field in New Mexico, in the region about Santa Fé and Albuquerque on the Rio Grande, and in the region near El Paso on the Rio Grande.

In New Mexico we have mapped 6,370 square miles; in California we did 6,680 square miles; in Idaho we did no work during the last year; this summer we have, however, done in Idaho 1,900 square miles, made a topographical survey of that; and in Montana we did 5,200 square miles. So that under the act creating the Irrigation Survey and the appropriations made therefor we have already made topographical maps over an area of 43,050 square miles.

I have another map hanging before you which will set forth certain other facts bearing on this subject.

The survey under the present organization and surveys previously prosecuted under the control of the present Director of the Survey have been made with a view that they might ultimately be used for this purpose. So that we now have a topographic survey ready for the use of the Irrigation Survey of an area of 250,000 square miles, and all of that work is finished, in the field and in the office. To this must be added the 43,530 square miles accomplished by the Irrigation Survey. The maps are in part in the engraver's hands, under contract by the Public Printer, for their engraving. About two-thirds of them are already engraved, and we have proof-sheets.

Senator REAGAN. What surveys are those?

Director POWELL. The surveys previously made under my charge. All the areas in blue are surveyed in this manner, covering altogether 250,000 square miles.

The CHAIRMAN. Do you reckon in that the King and Wheeler surveys?

Director POWELL. I am going to speak of those because they are also shown on this map. The Hayden surveys are marked in light blue. Those maps were not constructed to be used for this specific purpose, but the work of the Hayden surveys was done in such a manner that some additional cost is necessary to prepare them for use for this purpose. There are about 120,000 square miles to be completed in this manner. Again, the King survey is colored yellow. The King survey is not so well adapted to this work, and more has to be done on the area surveyed by King, that his maps may be utilized for this purpose; but probably the work can be done at one-half the cost of carrying on original work. The Wheeler survey, which is colored brown, as you see, and is scattered over the country, was done in the main on a scale of 4 miles to the inch, and for our purposes we need a scale of 4 and 2 miles to the inch. Then it was not constructed in contours, and hence is unavailable for the irrigation survey. The Wheeler survey serves as a general reconnaissance for planning topographic work, but not for irrigation work. So then altogether, besides what has been done under the appropriation for arid lands, we have 250,000 square miles of map ready for use; 140,000 square miles partly ready for use; 80,000 square miles on which much work is yet to be done, and about 100,000 square miles of reconnaissance work.

Senator PLUMB. In that connection let me ask you what if anything in the shape of monuments have been put on the ground which would indicate the altitude or meandering of the lines?

Director POWELL. In the work over which I have had control myself all the triangulations of the work in blue are marked in such manner that they can be re-discovered, are marked and described in the report.

Senator PLUMB. With the aid of these maps a local surveyor could identify them without resurveying them, I suppose?

Director POWELL. Yes.

Senator PLUMB. These maps would be, I suppose, what are called topographic maps, that is, they would indicate the slope and elevation, the contour, etc.?

Director POWELL. We divide the work into three classes, each of which is dealt with; the hydrography, which describes the courses of all streams, with all their meanderings; second, the hypsography, as it is called, the elevations of all the hills and mountains; third, the culture. The lines of all high roads, of all railroads, canals, town sites, cities, etc., the boundary lines of States and Territories, counties, etc., those things which man has put on the country and are represented on the map, we call "culture." These maps represent the hydrography, the hypsography, and the culture, or that which man has put on the ground.

Senator PLUMB. Then with the use of those maps the local authorities, or any one interested in the development of the country, would be able to understand the lay of the land just as though he himself had made the map?

Director POWELL. Precisely; the object is to construct maps in such manner that any man may go upon the ground, take the map in his own hand, and select the sites for reservoirs, and select the routes for canals with the map before him. On selecting the routes for canals, a subsequent survey would be needed for the purpose of determining the constructive elements—the fills, the grades, the cuts, etc., that would be necessary for a canal, but the general route of a canal can be planned on the map without going on the ground. That is true not only for every canal, but for every road and for every railroad. So that wherever, in the United States, the surveys have been carried on as shown on the map, no railroad company has to make a preliminary reconnaissance or trial-line survey. From our maps all such enterprises may select their routes before they go onto the field, and they systematically do that, and have been doing it for several years, and as far as our surveys have progressed.

There is one thing of importance that I wish especially to call attention to in relation to the topographic maps. That is, that in general the reservoir sites in any region of country are in excess of the wants. There are usually more reservoir sites than will be needed. The topographic survey reveals all practical reservoir sites, and hence reveals more than will be needed. There comes then to be a necessity for a selection of the best sites. And the topographic maps furnished then practically the chief data necessary for this purpose, as well as for other purposes which I have mentioned.

I am passing very rapidly, Mr. Chairman, and briefly over these points, because there is so much of the matter. If the members of the committee wish to ask any questions as I go along I shall be glad to reply.

In planning a system of irrigation work we are at once confronted with the question, What is the amount of water to be controlled and used? The lands are abundant, the water is scarce. The entire arid lands are naturally divided into irrigation districts, each one composed of a catchment area and a farming area, for in farming regions, where agriculture is carried on by irrigation, the lands which catch the rain and supply the water are not those which are cultivated. To select from a large tract a smaller one to be irrigated, it must first be determined

how much water the catchment area will furnish for the purpose, for on this will depend the quantity of lands to be reclaimed. The amount of water also determines the character of the irrigation works. More water requires larger dams, canals, and reservoirs; less water needs smaller works. The water running in the channels in each of these catchment districts—and there are many thousands altogether—is variable from year to year, from month to month, and even from hour to hour at flood time, and it becomes necessary to determine the mean annual volume, the minimum annual volume, the maximum annual volume, and the maximum volume of the floods. The mean annual flow gives the limit of general agriculture from year to year; the minimum annual flow limits the agriculture in seasons of drought; the maximum annual flow controls the plan of the works, for they must be constructed in such a manner that they will not be destroyed when it comes; the maximum flood volume also must be known, for this ultimately brings the greatest strain upon the works, and they must be constructed to withstand it.

In the plan of the survey the volume of water running in the streams of the catchment districts, and which is furnished to the farming districts, is determined by making a topographic map as a basis for a hydrographic survey.

The first process is stream gauging. The measurement of the streams is accomplished by a twofold process. First, a river-gauge is established, with a float, by which the height of the river is recorded automatically during the year. That is to say, a nilometer, as it is called, is established in such manner that the rise and fall of the stream lifts or lowers a float, and in lifting or lowering this float it records the rise or fall upon a paper by a little machinery attached to it; so that we have the record from day to day and month to month and year to year automatically recorded of the height of the stream. Then, the cross-section of the stream where the nilometer or river-gauge is used is determined for different heights of water. A continuous section from low water to high water is made, so that if we know how high the water is at any moment of the year we know the cross-section at that time.

Senator JONES. Does the nilometer show the length of time at which the river stands at any particular stage?

Director POWELL. Yes. It has clock-work, by which the whole history of the rise and fall is preserved.

Senator JONES. Does it show the velocity also?

Director POWELL. No, sir; I am coming to that. The next is the velocity of the water passing the cross-section. That varies in the different portions of the stream. It varies from side to center and from top to bottom, and it varies with every rise and fall of the river. It becomes necessary therefore to have another class of instruments, known as current-meters. By finding the mean velocity of the passing water and the cross-section of the stream we determine the volume of water passing for a given stage. Then we must find it for each stage marked upon the river-gauge or nilometer. This gives us the flow of the river. It is all plotted. If you remember, a plat of that kind was presented to you in Arizona.

With this river-gauging, then, we steadily gather the data to show how much water the river will carry—not at one time, but at all times, varying from day to day through the year.

It is in this manner that we gauge the rivers and creeks. The number of places where such "gaugings" must be made is very great. We have estimated that about 20,000 would be needed. To make that num-

ber of gaugings, each one for a series of years, so as to obtain the mean, maximum, and minimum annual flow and the maximum flood volume, would take a long series of years and would be enormously expensive. But a cheaper, shorter, and it is believed a more accurate method has been devised. This method involves the construction of a topographic map and the gauging of a few typical streams.

It is thus that attention is first called to the catchment area, and of this we must have a topographic map, which will show its superficial area, its declivities, and its altitude above the level of the sea. Other things being equal, the greater the area the greater the amount of rain caught. Other things being equal, the greater the declivities the greater the amount of water furnished to the streams, for flat lands with accumulated soils and sands hold the water back and by evaporation return it to the heavens. Lands with great declivities have less soil and sand, and their slopes gather more water into the natural channels. In the arid region of the United States there are altogether vast tracts, perhaps in all one-fourth of the entire area, where no considerable water runs off. There are other regions, altogether very extensive, where the slopes are so steep and rocky that the greater part of every storm runs down; and between these extremes all gradations are found. The water supply, therefore, is dependent upon declivity. The altitude of the catchment area is also an important factor, for within limits, other things being equal, the greater the altitnde the greater the rain-fall. To obtain altitudes, declivities, and areas, a topographic survey is necessary, and the topographic survey having been made, the cheapest and best method of assembling the facts, so that they can be understood, is to construct a contour map. The entire area of the arid country—including the low deserts where no waters flow away—is composed of catchment areas. Each tract or district is a catchment area—not for itself, but for some other district, which in turn is a catchment area for still another. It is thus that a map must be made for all parts of the country but the flat deserts, and they are included in the others, and in some cases constitute the irrigable lands to be farmed, for while they are desert without water, they are the *best* farming lands when irrigated. Hence, practically, the entire country must be mapped, and the flat lands are mapped without expense worthy of mention.

Now, to make this map serve for hydrographic purposes something more is needed. A few streams must be gauged. Suppose we have found a drainage area of 10,000 square miles with maximum declivities, so that most of the water is gathered into channels and passes from the catchment area to irrigable lands below. Here, where the water is all brought together in one stream, we gauge it and find how much water an area of that size having determined declivities will afford. Now, wherever we have another catchment area with similar declivities if the rainfall is the same we have to make but the topographic map to determine the water which it will supply. It is in this manner that the preparation of a topographic map is a part of a hydrographic survey. A few streams are gauged, the general rain-fall is determined, and the catchment areas are measured topographically so as to obtain horizontal and vertical dimensions.

The next part of the hydrographic work is to determine the amount of evaporation. When water is stored in reservoirs an amount, known in a general way but not known in a very close way, is lost by being returned to the air. In order to know how much water can be saved it is necessary to know how much will be lost in this manner, and at these

gauging stations we establish evaporating stations for the purpose of determining the amount of evaporation from day to day through the year. The machinery for this need not be described; it is very simple.

The next element in the hydrographic survey is the determination of the quantity of sediment carried in the water. All streams carry with them the drift of the slopes and hill-sides of the catchment area. Some streams carry much, others little. Some streams carry much at one part of their course and less at another part.

The life of a reservoir is an important factor to be determined, and this must be determined by discovering how long it will take under the conditions to fill that reservoir with sediment. In order that this may be provided against it must be determined how much material must be removed from the reservoir annually in order to make its life continuous. The streams therefore have to be gauged for sediment, and an apparatus is provided for the purpose. Connected with these stations we have rain-fall gauges wherever we have established work of this character. The reading of the rain-fall gauges takes practically but very little time, and we can do it without expense. But in the main we are assisted in this work by local enterprise. In most of the States and Territories the people have organized weather bureaus, or some system for determining temperature, rain-fall, winds, etc. We have it so arranged that all this material is aggregated in our office. In most of the States and Territories ultimately people will work uniformly on our system. They are asking us already to take general control of their plans and are gathering the facts necessary for our work, so that we do not have to perform that work ourselves to any great extent. In addition, we avail ourselves of the material collected by the Signal Service.

Besides the organizations to which I have referred, there are individuals who of their own will have organized such observation systems for themselves; and especially I may mention, in this connection, railroad companies. So that there is pouring in upon us from all parts of the arid lands a vast amount of information in relation to rain-fall, to temperature, and to the course of the winds.

I shall not weary the committee with a detailed statement of the hydrographic stations we have established; but I have the results of the work up to the present time in tabulated form in this paper, and with your permission I will simply hand it to the reporter that it may be incorporated with my remarks.

Summary of hydrographic results.

The daily average flow in cubic feet per second has been obtained for the following rivers:

COLORADO.

River.	Station at—	Results.
Arkansas	Cañon City	Apr. 17, 1889, to end of year.
Do	Seven miles above Pueblo	May 1 to Sept. 1, 1889.
Do	La Junta	May 20 to Sept. 1, 1889.
Do	Lamar	May 26 to Sept. 1, 1889.
Purgatoire	Las Animas	May 22 to Oct. 1, 1889.
Huerfano	Hermosilla	June 30 to Sept 1, 1889.

Summary of hydrographic results—Continued.

NEW MEXICO.

River.	Station at—	Remarks.
Rio Grande	Del Norte	July 1 to end of year. (Discharges at intervals, also measurements of canals.)
Do	Embudo	Dec. 20, 1888, to Nov. 30, 1889. (Daily discharge complete.)
Do	San Marcial	One gauging only.
Do	El Paso, Tex	May 10, 1889, to end of year (complete).
Jemes	Jemes Pueblo	Mar. 20 to Nov. 5, 1889. (Discharge partially computed.)

ARIZONA.

Verde	Above junction of Salt River	Discharge from Aug. 15 to Sept. 30.
Salt	Above junction of Verde River.	Discharge from Aug. 1 to flood at end of Nov.
Gila	Fifteen miles above Florence..	Discharge from Aug. 30 to end of year.

NEVADA.

Truckee	Essex, Nev	Discharge from May 20 to Sept. 30.
Carson		Few gaugings.
Purser Creek, Squaw Creek, Little Truckee, and all important tributaries.		Gauged in high water.

IDAHO.

Wood	Hailey	Discharge from June 23 to end of year.
Snake	Eagle Rock	July 1 to end of year.
Do	Above Fall River	One gauging.

UTAH.

Bear	Battle Creek	Discharge Oct. 15 to end of year.
Do	Collinston	Discharge July 22 to end of year.
Ogden	Ogden Cañon	Discharge Aug. 20 to end of year.
Weber	Weber	Discharge Oct. 15 to end of year.
American Fork	American Fork	Discharge Aug. 1 to end of year.
Provo	Provo	Discharge July 15 to end of year.
Spanish Fork	In cañon	Discharge Aug. 1 to end of year.
Sevier	Joseph City	Discharge Aug. 20 to end of year.
Do	Leamington	Discharge Aug. 20 to end of year.

MONTANA.

Yellowstone	Horr, Mont	Aug. 12 to Nov. 30, 1889.
Do	Springdale	Special gaugings.
Sun	Near Augusta	Aug. 5 to Nov. 30.
West Gallatin	Bozeman, Mont	Aug. 16 to Oct. 30.
Missouri	Cañon Ferry	Sept. to Nov. 30.

Also various canals, small tributaries have been gauged to furnish special data for use of division engineers.

Rain-fall measurements.

Locality.	Stations.	Measurements.
Arizona	30	June to Dec., 1889.
Colorado	10	June to Dec., 1889.
New Mexico	35	March to Dec., 1889.

Evaporation estimates.

[Monthly evaporation in inches.]

	1888.	1889.										
	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
Montana:												
Livingston	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	*3.2	2.9
Bozeman	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.5	4.3	1.9
Great Falls	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	†2.7	‡1.0
Springdale	.....	.....	.....	.....	.....	.....	.....	.....	‡6.8	‡7.1	.....	.....
Hogan	.....	.....	.....	.....	.....	.....	.....	.....	.....	†6.1	.....	.....
Utah:												
Fort Douglas	.....	.....	.....	.....	.....	.....	.....	.....	10.5	5.7	‡4.8	.....
Provo	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	‡3.3	.....
Arizona:												
Tempe	.....	.....	.....	.....	.....	.....	.....	13.7	14.1	11.0	6.4	4.4
Texas:												
Fort Bliss	.....	.....	.....	.....	.....	11.0	10.7	9.6	11.4	9.2	6.8	4.6
Colorado:												
Cherry Creek	.....	.....	.....	.....	.....	.....	8.1	7.9	8.6	6.2	4.2	‡2.6
New Mexico:												
Embudo	†6.0	3.0	2.9	3.6	4.9	.....	.....	.....	.....	.....	.....	.....

* Based on 16 days' observations.
† Based on 14 days' observations.
‡ Based on 8 days' observation.

SILT.

The amount of silt carried by the Rio Grande at Embudo, N. Mex., was measured from January 15 to April 15, and by the Rio Grande, at El Paso, from June 10 to the end of the year (when the river was flowing).

Average volume of water (according to the assumption that a cubic foot of dry sediment weighs 85 pounds).

	Embudo, N. Mex.	El Paso, Tex.
	Per cent.	*Per cent.*
Minimum	.0014	.0139
Maximum	.0413	1.4167
Average	.0101	.3865

The third part or branch of the survey relates to the locating or planning of irrigation works—the engineering branch as we call it. So that we have three branches—the topographic, the hydrographic, and the engineering—under different managements, in general, in the field, needing men specially trained in each to accomplish the work properly.

The basis of the work of the engineering branch is the topographic survey and the hydrographic survey. The outcome of the work, the purpose for which it is all done, is not realized until the work of the engineering branch is finished. The organic statute of the survey provides that we shall select diverting dam sites, canal sites, and reservoir sites, and withdraw the same from market that they may remain in the possession of the General Government. It also provides that the lands to be irrigated shall be segregated that they may be obtained only under the provisions of the homestead act. All of these sites and lands have to be discovered. In their discovery, the entire country has to be overlooked or surveyed, and this is the work of topography. Usually there are many more reservoir sites than are needed and the best should

be selected; for this purpose all must be discovered; water should be stored in the mountains whenever it is possible, as there is less loss by evaporation there. All the mountain reservoir sites must, therefore, be discovered; but a part of the water falls upon the foot-hills and valleys, and that also must be stored. So there must be reservoirs below, and this lower region must be examined. Wherever it is possible we must store the water away from the streams so that the reservoirs may not be destroyed by floods. But this is not always possible, so the whole ground must be studied for reservoir sites, then the stream channels themselves must be studied for dam sites.

Then there are canal sites from the diverting dams to the reservoirs and from the reservoirs to the lands to be irrigated, and these canal lines must be discovered. In any basin many possible lines may be found; the best should be selected, to make this selection all must be known. When there is more land than can be served by the water, the best should be selected; to do this all must be known. Now the topographic survey discovers all possible reservoir sites, all possible dam sites, all possible canal sites, and all possible irrigable lands, then constructs a map with all these facts shown upon it. The engineering survey now steps in to complete the work and the selections are made by an examination of the map, which is a miniature counterpart of the country with quantitative elements represented by contour lines. It will sometimes happen that two lines or two reservoir sites have advantages so nearly balanced as shown by the topographic map that a choice can be made only by a more refined examination. But in general the special sites will be discovered on the map. Now, these special sites must all be examined in a detailed manner in order that the works may be planned, and such refined surveys are expensive and it is necessary to reduce them to a minimum, which the preliminary topographic survey accomplishes—the topographic survey is a preliminary or reconnaissance survey to discover what the refined and costly work of the engineering survey must do, and is a great saving of expense.

While I can not go over all the ground which we have covered in this work, I have brought a few examples to illustrate what is done, and have brought this map with me to show what the survey will be when it is finished. I would like to have you consider first the Arkansas Valley. (See map.)

All the works on the Arkansas are not yet planned, but something has been done, and one illustration may be presented. On the Arkansas we have discovered a number of reservoir sites. This is the first reservoir which we planned on the Arkansas, and it is incomplete. Here we have a map with grade curves of the Twin Lakes, high up on the Arkansas River. These are 5-feet grade curves, showing the outlines and the outlet to the lakes. Here [indicating] is the outlet, and a section across here shows where the dam is to be constructed. In Arkansas twelve reservoirs like these have been surveyed in detail, maps drawn of them, and data secured for all estimates of capacity and cost, but the data has only been collected, and it has not yet been assembled, so that I can not report it. The Twin Lakes which you see here have a capacity of 100,000 acre-feet. That is a capacity, under proper conditions, to store water for the irrigation of 100,000 acres. The cost of the reservoir will be about $60,000, and the cost of the canal, to bring the drainage of another stream into this, so that all may be stored into one after awhile, will be about $75,000. The total cost therefore will be about $140,000 for the whole system of works, to store 100,000 acre-feet of water, or about $1.40 cents per acre-foot.

Senator REAGAN. By acre-feet, do you mean a foot deep on an acre of ground?

Director POWELL. Yes, sir; an acre-foot of water is an acre of water 1 foot deep. When irrigation, under average conditions, is practiced with economy, it is believed that an acre-foot of water will supply an acre of land for one year, and we adopt that as being convenient for many purposes.

The CHAIRMAN. That will vary somewhat, of course?

Director POWELL. It will vary very greatly. I am giving only a general and mean figure.

On the Arkansas now fifty reservoir sites have already been discovered. Of these, twelve of the most promising have been studied with much care and the data collected, as I have said, for their plans. The data collected show that we can store, on the sites for the reservoirs already selected, water enough to irrigate three times the amount of land now cultivated, so that the whole area cultivated on the Arkansas will be three times as much as that now cultivated.

Senator CASEY. And that total would be what, do you remember?

Director POWELL. I have the figures at my office, but I have not them with me.

The Rio Grande is the next that I shall present to you. The other work, as I told you, is unfinished and it would be difficult to present the real work without the figures and papers.

I now show you a plan of the work for the storage of water on the Rio Grande, immediately above El Paso. The Rio Grande flows from the left to the right of the map. The dam is to be constructed at this point [indicating a point on the right of the map] and a topographic survey has been made, not only of the sites of the reservoirs, but also of the larger part of the region above El Paso, for the purpose of determining the region of country upon which this reservoir must in dry seasons depend for its water. The maps are not constructed in the office, but the data is at hand and draughtsmen are at work on them at the present time. With a 60-foot dam this reservoir will store 537,000 acre-feet, and we expect to find water sufficientf or that purpose, but of this we are not yet sure, as the survey of the entire area is not yet finished. The estimated cost of this reservoir is $1,100,000.

The CHAIRMAN. That is, the reservoir, without the condemnation of land?

Director POWELL. No, sir; with a detailed project.

The CHAIRMAN. Covering all?

Director POWELL. Covering all. There are, running along the course of the Rio Grande, two railroads, and I have had the engineers of the survey run lines outside of the reservoir sites (for the railroads run into the reservoir sites) and to compute the cost of the construction of such roads, and have assumed that the reservoir would cost not only the amount necessary for the construction of the dam, but for the construction of lines of roads which would take the railroads out of the reservoir sites.

The CHAIRMAN. Does that embrace the land to be condemned?

Director POWELL. That embraces the land to be condemned.

Senator JONES. Where on this map is the dam to be constructed?

Director POWELL. Along here, at this point [indicating].

A final report of the irrigation district to be served by this water, will embrace, first, a map of the district where the water is to be caught, extending over the district where the water is to be used—the irrigable land, as you see; second, a map of the region on a large scale. Then

plans for dams, canals, and all the engineering work necessary to go with it.

The CHAIRMAN. That will only include the portion on our side of the United States?

Director POWELL. On our side.

The CHAIRMAN. The other side will be about the same but a little larger, probably.

Director POWELL. In California we have discovered a good many reservoir sites. The best one is on the Monaco Meadows, in Kern County, which has a capacity of 320,000 acre-feet. The survey of one site has been completed, that of Clear Lake, near San Francisco. The results are not yet finally on paper. An extended reconnoissance has been made in California, in Butte and Lassen Counties, and two large reservoir sites have been discovered there. Altogether fifteen reservoir sites have been reported for withdrawal, and about forty more will be reported soon, in California. But I have them tabulated elsewhere.

In Nevada, surveys have been made on Weber Lake, Independence Lake, and Donner Lake, in the Truckee Basin, and also in Hope Valley and Long Valley, in the Carson Basin. A canal line has been surveyed, to extend for some miles above Wadsworth. It was intended at the beginning of the season this year to make a careful study of Tahoe Lake to be used as a reservoir. A study was made of it, but it was unsatisfactory and the work will have to be done over—the theory on which it was made being wrong.

In Idaho the work has been done on the Snake River and its tributaries. The Snake, or Shoshone, River, is one of the great rivers of the Western region, and a series of reservoirs has already been discovered. Here on the map is the Snake River. It heads, as you see, in Wyoming. A large part of the water of the Snake River must be stored in Wyoming, in the high mountains where the rain and snow are accumulated. In that region of country we have discovered three very fine reservoirs. The Jackson Lake reservoir, which you see here, will store 1,000,000 acre-feet of water at a cost of $250,000, or at the rate of 25 cents per acre-foot. The Swan Valley reservoir, which you see here, will store 1,500,000 acre-feet of water, at a cost of 25 cents per acre-foot. We have plans for these dams ready. The Fall River reservoir, which you see here, and which will be partly in the Yellowstone Park, partly in Wyoming, and partly in Idaho, will store 500,000 acre-feet of water with an inexpensive dam, but the cost of construction of the dam is yet unknown. Several canal lines have been run along the Snake River at different places, to find out where this water can be used. The water stored above must be used below on the plains, here, in the main in Idaho. The region of country in Wyoming and in Yellowstone Park is not an agricultural region.

Senator JONES. Is there water enough in the water-sheds of these reservoirs to fill them?

Director POWELL. Yes, there is ample water; much more than we are yet able to store.

The waters of the Snake River and its tributaries, properly taken out, and taken to the high lands, first, and recovered after irrigating the high lands and again used on the low lands—from the facts which we are now in possession of we are able to say that at least 10,000,000 acres of land can be redeemed.

Senator JONES. That is, as it now is?

Director POWELL. No; but by the utilization of the river, by canals, and reservoirs, complete. This will involve the construction of a number of reservoirs, the sites of only three of which are now planned or known, though in a general way we know of others.

I shall pass from the Snake, rapidly, to speak of the Montana work. In Montana we have done work on the Gallatin, the Madison, and the Jefferson Rivers—the rivers which unite to form the Missouri—and we have done work on Sun River to the north of them, and we have done work on the Yellowstone River, during the past season. I can not detain you long enough to explain all of these works. The plans which I have brought with me this morning relate to Sun River, and I shall be able very briefly to lay before the committee a very interesting system of works.

The general plan of the Sun River is here on a very small scale, because the topography is not finished. On the first map the course of the river, the lands that can be irrigated, and the sites of the canals are delineated.

The second map which I present shows the plan of reservoir No. 1, marked on the first map. The reservoir itself is illustrated by this map. The dam on the river is at this point. These are grade-curves of 4 feet elevation; passing from one line to another you rise 4 feet; so that anywhere you can make a section across the reservoir that will enable you to compute the capacity of the reservoir. The site of the dam is at this point [indicating]. The capacity of this reservoir is 43,000 acre-feet. The plan of the dam itself it shown on this diagram.

These maps which I now show you of the Sun River illustrate the character of the report we are going to make of that region. The first, the general topography on which are placed all reservoirs and canal sites; second, a sheet exhibiting such reservoir and each canal by itself; and third, a sheet like this (exhibiting the elements of construction in the works themselves), and all to be accompanied with text or written explanations, including the elements of cost, etc., with directions of how to construct the dam.

Reservoir No. 2, on the Sun River region, is represented on this sheet. It has a dam shown on the corresponding sheet, which I hold in my hand.

The CHAIRMAN. How large is that?

Director POWELL. It has a capacity of 65,000 acre-feet.

On the map we have a plan of the waste-weir. I need not exhibit to you all these plans; we have plans of waste-weirs, of dams, of reservoirs, and of canals, and the course of the river and a part of the topography. I think that is sufficient. I need not go into details. It is a small river and we were able to complete it in a short time.

The CHAIRMAN. Have you figured up the expense of those dams?

Director POWELL. Yes. That will be inserted in the record also. I have it in my tables.

We find that the water of the Missouri can be taken out below Helena, near a town called Toston, a very favorable point, so that at that point all the water that is not used above in the Gallatin, Madison, and Jefferson Rivers can be extracted from the river and poured out on lands of great value.

The CHAIRMAN. How much of the river is above that point?

Director POWELL. It is a very large river above that point.

The CHAIRMAN. There is a large water-shed above that?

Director POWELL. Yes, a very large water-shed. The whole of the valleys of the Gallatin, Madison, and Jefferson lie above it, and the

whole drainage area from Yellowstone Park down to that place. At that place it is possible to take out all the water stored in the reservoirs above.

The CHAIRMAN. How extensive is the region that would be covered?

Director POWELL. The canal line is about 72 miles in length, and will cover a broad section of country, varying from 20 to 30 miles in width. Below that point the river cañons in places, and I do not really know much about it except from general topographical information; practically we have no engineering data on which to speak.

On the Yellowstone, the chief reservoir on which we have worked is the Yellowstone Lake, which lies in the park. A magnificent reservoir can be made out of it at a cost comparatively trifling—simply opening up 2 or 3 miles of channel below and putting in a head-gate and controlling the river, so as not to lift the lake at all, but to drain it down 2 or 3 or 4 feet each year, so that it will never be higher than it is now.

The CHAIRMAN. That would be very cheap then?

Director POWELL. Yes. The chief cost of the work will be in the construction of the canal. The immediate valley of the Yellowstone furnishes only in places favorable sites for irrigation. It is in part subject to floods now, and in part subject to cloud-bursts that strike the cliffs and bad lands on each side, and these cloud-bursts on the cliffs and bad lands destroy irrigation works below. Then there is not enough land lying in the immediate valley to utilize all the waters of the Yellowstone or any very considerable part of them when they come to be stored. We hope to be able to carry the water out near Livingston on to the mesa lands above without serious engineering difficulty.

The CHAIRMAN. What is the character of those lands generally?

Director POWELL. They are partly rolling; many of them have gentle slopes. Altogether these lands are as good as there are in the world for agriculture.

The CHAIRMAN. They are not too high up?

Director POWELL. No; they are good wheat lands. The operations of the survey have been extended in another direction. The statute requires that we shall determine sites of reservoirs—segregate them from the public lands, and report them to the Secretary of the Interior and to the land department, and under that statute they are withdrawn from sale that they might be used by the people as reservoirs. We have made a number of these selections, and all of them I have in a table before me, but I shall not read them now. It would take too long, and the matter is too statistical for an occasion like this, but I will hand the table to the stenographer, and he can insert it in my remarks. The table embraces only a very small part of the reservoir sites that have been discovered, and includes only those which the engineers have selected. Many others will be selected out of those already discovered.

COLORADO.

No.	Name.	County.	Drainage basin.	Capacity.	Delivery.	Cost.
				Acre-feet.	*Acre-feet.*	
1	Twin Lakes[1]	Lake	Arkansas.	Very large.	125,000	Very moderate.
2	Leadville[2]	do	do	10,000	7,000	Do.
3	Clear Creek No. 1[2]	Chaffee	do	10,000	10,000	Do.
4	Hayden[3]	Lake	do	62,000	62,000	Very large.
5	Sugar Loaf[4]	do	do	18,000	10,000	Moderate.
6	Crane	do	do	2,000	2,000	Rather large.
7	Tennessee	do	do	20,000	12,000	Moderate.
8	Cliff Creek[5]	do	do			
9	Cottonwood Lake[6]	Chaffee	do	15,000	15,000	Very large.
10	Clear Creek No. 2	do	do	2,000	2,000	Moderate.
11	Wilson Creek	Fremont	do	4,500	4,500	Very large.
12	Oil Creek Valley	do	do	7,500	7,500	Do.
13	Slate Creek	El Paso	do	3,500	3,500	Prohibitory.
14	West Oil Creek	do	do	2,000	2,000	Large.
15	High Park	do	do	30,000	30,000	Very large.
16	Cottonwood Creek No. 1.	Fremont	do	3,000	3,000	Moderate.
17	Cottonwood Creek No. 2.	do	do	2,000	2,000	Prohibitory.
18	Beaver Creek No. 1	do	do	2,500	2,500	Large.
19	Beaver Creek No. 2	do	do	2,000	2,000	Do.
20	Middle Beaver	El Paso	do	1,200	1,200	Very large.
21	Seven Lakes	do	do	6,000	6,000	Large.
22	Yorkville	Fremont	do	3,000	3,000	Prohibitory.
23	Big Turkey Creek	Pueblo	do	5,500	5,500	Very large.
24	Six Mile Creek	Fremont	do	3,000	3,000	Do.
25	Eight Mile Creek	do	do	13,500	13,500	Do.

[1] A thoroughly good site.
[2] Good site.
[3] Cost probably $1,000,000 or more.
[4] Fair site.
[5] Small site; its delivery can be made part of Sugar Loaf Reservoir.
[6] Possibly not prohibitory but doubtful.

CALIFORNIA.

1	Clear Lake[1]	Lake	Clear Lake	Very great.	Small	
2	Independence Lake[2]	Nevada	Truckee	35,000	20,000	Moderate.
3	Weber Lake[3]	Sierra	do	15,000	10,000	Do.
4	Donner Lake[4]	Nevada	do	45,000	25,000	Do.
5	Monache Meadows[5]	Tulare	Kern	350,000	(?)	Do.
6	Big Meadows[6]	do	do			
7	Little Yosemite[6]	Mariposa	Merced			
8	Tenaiya Lake[6]	Tuolumne	do			
9	Tuolumne Meadows[6]	do	Tuolumne			
10	Eteanor Lake[6]	do	do			
11	Kennedy's Meadows	do	Stanislaus			
12	Kennedy's Lake[6]	do	do			
13	Bear Valley	Alpine	do			
14	South Highland Lake	do	do			
15	Rattlesnake Creek No. 1.[7]	Modoc	Pit River	Very large.	Large	Moderate.
16	Rattlesnake Creek No. 2.[7]	do	do	do	do	Do.

[1] This lake has been thoroughly surveyed, but reports not yet received. Office work has not reached stage of estimates.
[2] A very good reservoir site.
[3] A good site.
[4] A very good site.
[5] Delivery will probably be very large; present indications are that this is the most effective site now known in California.
[6] These reservoirs have been reported worthy of examination and survey. No estimates practicable at present. In a general way most of them will be costly in proportion to delivery; some probably too costly.
[7] Present indications are that these two are very valuable reservoir sites of large delivery. Not yet surveyed.

IDAHO AND WESTERN WYOMING.*

[Snake River Basin.]

No.	Name.	County.	Drainage basin.	Capacity.	Delivery.	Cost.
				Acre-feet.	*Acre-feet.*	
1	Jackson Lake[1]	Fremont County, Wyo.	Snake, South Fork.		1,000,000	Small.
2	Swan Valley[2]		do	1,500,000	1,500,000	Do.
3	Falls River[3]	Yellowstone Park.	Snake, North Fork.		500,000	Do.
4	Blind Creek	Elmore	Boisé		160,000	Do.
5	Fair Creek	do	do		60,000	Do.

[1] Capacity much greater than possible delivery. The delivery depends upon unsettled questions. If the proportion of precipitation which runs off from the water shed is nearly as large as in the case of Yellowstone Lake its delivery may exceed considerably 1,000,000 acre-feet.

[2] There is no question that the water supply is ample, and more than sufficient to fill this basin.

[3] Capacity probably much exceeds the inflow.

*The storage capacity in the Payette and Weiser Valleys is known to be large, but has not been surveyed. There is also a large portion of the Upper Snake Basin which remains to be even reconnoitered for sites and there is no reason to suppose that the above approximates the limit of storage possibilities in that basin.

MONTANA.†

1	Sun River System, No. 1.	Lewis and Clarke and Cascade.	Sun River.	12,000	12,000	Moderate.
	2	do	do	13,000	13,000	Do.
	3	do	do	63,000	63,000	Do.
	4	do	do	42,000	42,000	Do.
	5	do	do	65,000	65,000	Do.
	6	do	do	12,000	12,000	Do.
	7	do	do	3,000	3,000	Do.
	8	do	do	3,500	3,500	Do.
	9	do	do	2,000	2,000	Do.
	Yellowstone Lake		Yellowstone.		1,300,000	Small.
	Logan Valley		do		250,000	Moderate.
	Beaver Head, No. 1		Beaver Head.	500,000	400,000	Do.

† There are a large number of great reservoir sites not mentioned here which have been reconnoitered, but only to a sufficient extent to determine the fact that they have good dam sites, and a large water supply. Any estimate of their actual capacity and delivery would at present be premature. On the Madison River, Mr. H. M. Wilson is of the opinion that there is storage capacity with full delivery for at least 800,000 acre-feet at a low cost per acre-foot. On the Jefferson and its forks there is nearly as much. Sixty-two reservoir sites, all of which are believed at present to be practicable and moderately costly have been reported for withdrawal in Montana. Their united delivery may be roughly estimated at not less than 4,000,000 acre-feet.

UTAH RESERVOIR SITES.

1	Utah Lake[1]	Utah	Salt Lake.	Very great	Not great.	Small.
2	Gunnison[2]	San Pete	Sevier	2,000	2,000	Do.
3	Bear Lake[3]	Rich	Bear River	Very great	Problematical.	Large.
4	Desert[4]	Millard	Sevier	800	800	Small.
5	Cottonwood[5]	Salt Lake	Salt Lake.	Small	Small	Large.
6	Panguitch Hayfie'd	Garfield	Sevier	Very large	5,000	Moderate.
7	Plateau Valley	do	do	Moderate.	2,500	Do.
8	Panguitch Lake[6]	Iron	do	25,000	11,000	Very small.
9	Marysvale[7]	Pi Ute	do	10,000	10,000	Rather large.
10	Otter Creek	do	do	25,000	23,000	Moderate.

[1] Surface 140 square miles; lake shallow; maximum depth only 14 feet.

[2] Projected; not constructed.

[3] Water-shed now draining into lake relatively very small; area of lake, 120 square miles. Dam site doubtful; can be filled by diverting Upper Bear River.

[4] Projected; not constructed.

[5] Valuable as possible source of supply of water for use of Salt Lake City. Too costly and too small for irrigation.

[6] An excellent site.

[7] Cost probably not prohibitory.

Senator REAGAN. That is a list of the reservoirs that have been selected?

Director POWELL. That is a list of those already selected and defined. The list is arranged by States. It will be seen that there is a large number.

Irrigable lands have been segregated in the same manner, and all segregations have been completed in Montana.

The total amount of lands selected as irrigable in Montana is 11,500,000 acres; in Idaho the total amount of land selected as irrigable is 10,900,000 acres; in Utah the total amount of land selected as irrigable is 2,200,000 acres.

There will be reported in a few days in our office for the State of California 1,800,000 acres; and for New Mexico, on the Rio Grande and in the Rio Grande Valley, 5,200,000 acres, all of land segregated as irrigable land.

I thought I would bring here our method of record. I have brought a map showing where irrigable lands of Montana are situated which have been designated. They are colored green. In the aggregate about 30,000,000 acres of land have been segregated and withdrawn from the market to be offered to the people for homestead entries, as the statute provides. There have also been withdrawn many miles of canal lines. The sites of these lines remain, under the statute, in the possession of the Government, as I understand it. In the same manner many hundred reservoir sites have been withdrawn from the market, enough to store water sufficient to supply many millions of acres.

In a very brief manner that outlines the work that has been accomplished with the appropriations that have been made in the last two years, amounting in all to $350,000. It is not all expended; there being a sufficient amount of money on hand to continue the work until the 1st of July, partly in the office and partly in the field.

The CHAIRMAN. What length of time would it take to do the engineering work, or how early could you do it so that the people may know where to locate the reservoirs, etc.? How long would it take to do sufficient work in each State for all practical purposes, so that they could have it in hand?

Director POWELL. That is a difficult question to answer; it depends on the rate of appropriations.

The CHAIRMAN. Of course I do not expect exactness in the answer; but I would like to know about what rate of progress you can make.

Director POWELL. I think it would take a long term of years at the rate at which we are now going. It would take fifteen to twenty years at the rate at which we are now going. It was understood when the estimates were made that that work would go on very much faster hereafter than now—I would like to get it all done in six or seven years. At the rate of appropriation on which the original estimates were made we ought to get the material practically ready in seven years, and one-seventh of the work can be done each year.

Senator JONES. With what amount of annual appropriation?

Director POWELL. About $1,000,000 a year; that is if we have to segregate the lands and do all those things which the act of 1888 and the subsequent act of 1889 impose upon us.

The CHAIRMAN. Suppose you were to leave out all except the reservoirs, and the points at which the ditches were to be taken out, how long would it require, how rapidly could you designate the reservoirs and the points, leaving out the surveys of lines further than would be necessary to designate the proper places?

Senator JONES. You have to have the survey made, I suppose, before you can tell definitely?

Director POWELL. I can not do final work in any one basin without completing it all in that basin, and no part of the work is available for the people of such basin until it is all finished. We can not plan a system of works by piecemeal. We can not commence at the wrong end and plan backwards. We can not plan a reservoir and then afterward discover its site; we must know its site first. We can not plan until we know the amount of water which will be furnished to it, and by what diverting dam and what canal the water can be brought to it, and what lands can be irrigated by it, and what canals must be constructed from the reservoir to the lands. That is, we must discover the facts upon which the plan is to be based before the plan is made. We can not make the plan and afterwards discover the facts to fit it. The topographic survey must come first. The facts must be discovered by some method or other, and the topographic method is the cheapest way of discovering the facts, and the most accurate, and the most speedy. It would be possible to plan works by guessing at the facts, but when the plans were finished they would be worthless; perhaps they would be inadequate to serve the purpose; perhaps they would be extravagantly expensive because made on too elaborate scale. But the greatest danger of all would be to plan works which would not withstand the floods and be destroyed. The fortunes of the people depending thereon would then be wrecked, and in all probability many lives lost. It would be foolish and dangerous to plan the works ignorantly without regard to the facts which should govern their construction. Such a course should not be contemplated. The only question which can arise is, what is the best method of obtaining the facts; how can they be accumulated economically, thoroughly, and speedily?

Senator JONES. The surveys may show that such preliminary locations are bad. You have to make the surveys before you can know?

Director POWELL. I do not think it is wise to give to the people plans for reservoirs and canals, and designate lands on which these waters may be used, until the surveys are completed, except to say that "these places are reserved." I mean as it is completed from year to year; certain areas can be ready every year, but the whole of the States and Territories would take seven years, as I have said.

The CHAIRMAN. We will have a number of different localities in which the people will be anxious to get to work, and a good deal of pressure will be brought to bear upon us all the time. I want to see how this can be relieved.

Director POWELL. We propose to relieve the whole situation by taking the most densely settled areas first; then it must be understood that there is a certain amount of irrigation in every country which can go on independently of all surveys. There are small streams, springs, creeks, etc., on which the people can go ahead themselves. This general survey has its chief importance in connection with the great rivers, and with large creeks and streams, where large reservoirs may be constructed.

In some places the people's work is carried as far as possible, and where irrigation has been developed as far as possible by this means we are pushing in, first to show how that industry may be developed by the larger projects. But none of these will cut off the minor irrigation work. The major irrigation, the larger enterprises, will be developed from region to region in each State and each Territory as these

at what depth they lie and as to their character, whether they be pervious or impervious to water, but go in with a general statement to the people that it seems to be a good country for the boring of artesian wells, and if it should afterwards turn out that it is not a good country for that purpose our reports would be of no practical value. Unless we should be able to say positively "Bore here, and you will succeed; if you bore there you will fail," the reports would be of no practical value.

In order to be able to say to the people "You can do this and you can not do that," you will require a map based on a survey. Geology is expressed in topographic features. The map-making collects and arranges these facts of geology in a manner the most economic. All sound geology is based on topography. No good conclusive geologic work is done in the world without this basis.

The CHAIRMAN. In passing through that section of the country the committee took all the testimony that it could get regarding the condition and the character of the rocks. Suppose now that the United States should make a reasonable appropriation for additional wells to determine the extent of that basis, and an intelligent man, a geologist if you please, were to diligently inquire and make a careful record of what had been discovered—of course your experimental wells would determine in other places—might you not with one or two intelligent men to observe and record what has been done, and with the Government making some more wells, determine with considerable certainty so that the people might see where they could sink wells, so as to be making a practical move?

Director POWELL. We can take the artesian basins that we know of. Some of these basins are pretty well discovered and defined, as I have said before. We can say to the people as to certain places, "Bore here" or "Bore there."

There are other places where the artesian basins are not well known, but experiments have been made in them. There are others it is probable now entirely unknown. We know that there are some artesian basins, but we do not know their outlines. One man bores in one place and gets no water. The money of the man who gets no water is therefore lost. To trace the outline of that basin and be able to say to the people "You can bore and get water but if you bore 1 or 2 miles away you can not get water," that we can not do until we have studied the geological structure.

The CHAIRMAN. Yes, but that takes a good deal of time. The people are on the ground, and they are boring wells. Their hope is predicated on the prospects of getting water. My idea is to aid them in what they are now doing by collecting the facts as to the penetrations——

Director POWELL. That we are doing.

The CHAIRMAN (continuing). Doing that carefully—ascertaining the levels at which they will have struck water, formulating the information as fast as possible, and giving them all the knowledge available; and then, under an intelligent man, having some Government money expended in boring other wells to relieve them of the experimental expense. I have received I suppose twenty or thirty letters from enterprising men in that section, and one from a gentleman in New York, the other day, who said that he owned some land there and wanted to sell it to settlers. He wanted to know what information there was to be had as to the developments that had been made there in artesian wells, and what the Government could do or would do. It occurred to me that it would be well if you could have somebody who

was a good geologist to classify what has been done, without waiting for the topography—without waiting for the general geological survey; simply to classify what well-sinking has been done; and then to let some chances be taken, without speaking with absolute certainty, but giving them all the facts, as to where water is found. They will not want to wait until you have done all your work, so as to be able, as you say, to speak positively. They want to do something right away. The people are there and want immediate relief.

Senator CASEY. Will you be able to determine the limits of that basin without the experimentation?

Director POWELL. No, sir; not fully.

Senator CASEY. Is it not better to immediately proceed with experimentation to ascertain the expanse of those basins, instead of waiting for the topographical survey that will involve considerable time and expense? The very fact that the Government is taking an interest in this matter will be of great value to the people of that country. Their courage will be greatly aided. As to a topographical survey, the average citizen knows nothing of it. If he sees a hole being bored in the ground he knows what that means; he knows that it means business. The more important part of the country to water is the uplands, away from the river. What the people desire is that they shall know whether they can have water. Coming over this country, for instance toward the Red River, they will want to know whether they can get water, and at what expense. Can not that be ascertained by experiment, and can not the other work be followed up as inaugurated? That is to say, can not the beginning of the work be the boring of experimental wells?

Director POWELL. The work which is to be done there can be considered from two stand-points. It can be considered from the stand-point of what will be known when it is finished, or it may be considered from the stand-point of its progress—what will be known in the stages of its progress.

While the topographical work is going on, as I should work, the geological work is going on, the experimentation is going on; and the geological work is confirmed, as it is going on, by the experimentation. And when it is finished we will know the whole thing; but we will only know parts, as we finish the work in parts, as we go along. But as we go along the work will be developed *pari passu*.

Senator MOODY. The people who have sunk these wells are not scientific people, but mere well-diggers. The information which they have obtained they have not preserved.

The CHAIRMAN. Some of them have.

Director POWELL. We have more facts than they dream of.

Senator MOODY. They have not the facts which would enable them, or enable a scientific man, to determine the strata and the extent of the basin and all that. Of course you are aware that right here on the banks of the Missouri River, the very southernmost point of South Dakota, they have several wells. We know the fact, of course, that they were obliged to go only from 450 to 650 feet, according to the elevation on which they started, to strike that basin which brings the water to the surface with force, and of course we know the fact, for it is a familiar one, that the pressure there is from 60 to 80 pounds to the square inch. The other day they struck a well at 760 feet at Huron. They had to go 900 feet elsewhere. They got a well at Redfield at about 1,100 feet, and so on. They had to go as far as 1,300 feet on the divide between the Jim River and the Missouri River.

Here is a quartzite stratum along the eastern side of North and South Dakota. That red quartzite which they call jasper, sometimes granite, they have attempted to go through, but they have never found any water at any depth that they have gone through that. So we call that the "rim," or the "rim-rock." No experiments have passed over the Missouri River, or over the divide, in fact they have not got quite on the divide.

Now, the query is whether it would not be advisable to put a force into the field at once for the purpose of making a fairly good survey to show what area of this country can be utilized for irrigation—to experiment with this water—to see for example whether there is anything in the water which would be detrimental to crops.

The CHAIRMAN. I think the water is very good.

Senator MOODY. And then to dig experimental wells over west and across along the Missouri. Where we get across into the western part of the country we know there is plenty of surface water, and people are using the surface water for irrigation; they are constructing ditches in this region of country. One of these ditches is 25 miles long. But going farther north, into the western part of North Dakota, we do not know how much use can be made of the waters. What we want is that these people already there on the ground—600,000 people are located there—may know where they can get water. The farmers will have to depend upon bringing water to the surface to furnish moisture either in the atmosphere or upon the lands, because there comes sometimes a series of years in which they do not have sufficient rain-fall.

Senator CASEY. And four-fifths of the people are farmers and directly dependent on their farms.

Senator MOODY. Now, as Senator Casey has said, what these people want is courage. The courage of conviction is what they greatly desire, and if the Government will give them sufficient money to dig experimental wells they will take care of the rest.

Senator CASEY. But their courage must be built on that which is palpable to their eyes. They can not be expected to look upon this question from a scientific stand-point at all.

Senator MOODY. They want results.

Director POWELL. But what shall the people be given courage to do, to bore wells where they will ultimately fail or to bore wells where they will meet with success? Suppose they are advised to bore wells on barren ground; the first failure of that kind would react and all courage would be lost. I do not wish to give the people courage to lead them on to failure, to waste their energies in seeking disaster.

Senator MOODY. Will not the expenditure of a few thousand dollars there by the Government absolutely determine the question as to where that artesian belt exists and where to bore?

Director POWELL. Artesian water can be discovered in part by experimentation and in part by tracing out the formation of the ground.

Senator MOODY. And one must go with the other, you think, or ought to go with it?

Director POWELL. Yes, precisely. The geological examination without the experimentation will more or less be futile. The experimentation without the geological examination will be wasted. That matter has been up before Congress again and again, and appropriations have been made for Texas and Colorado. Fifty thousand dollars has been expended by the Government and thrown away, and yet there are artesian waters in that State. But the wells were bored without the examination of the geological structure and were not placed where the water was to be found.

Senator MOODY. Is it not practical with a comparatively small appropriation or expenditure for you to put into that country a corps of engineers and others right at once?

Director POWELL. I have estimates sent to the Secretary for each of the Dakotas of $50,000, with the idea that the work there was pending, that it was necessary, and that they wanted the work done at the earliest possible day.

Senator MOODY. Fifty thousand dollars for each of the Dakotas?

Director POWELL. Yes.

Senator MOODY. Is that enough?

Director POWELL. I have asked for $50,000 each for North Dakota, South Dakota, Nebraska, Kansas, and Texas, to be used in this work. With that amount of money I propose to take up, first, the study of the artesian waters and storm waters. My judgment is that the storm waters will be most valuable. I want to be frank with you. I think the people are mistaken, but the people believe in the artesian wells and I am going to meet them.

Senator CASEY. And the population lies where the storm water is not available without very great expense, such as the tapping of the Missouri, or something of that kind.

The CHAIRMAN. Oh, no.

Senator CASEY. I am living in that region and am familiar with it.

Director POWELL. My idea is that the people are looking to the artesian waters, and I should push artesian examination first; but I believe that it will be but a small resource, and that the great resource will be in the storm waters and river waters.

Senator CASEY. The experimentation is different in our case, because there are facts that exist from which you may proceed, and the examination of the basin should be from what is known outward.

Director POWELL. Yes; you have artesian basins but how much water will they supply is the vital question.

Senator CASEY. That is a different thing from an examination in a country where no well has ever been discovered.

Director POWELL. Already we have facts in relation to the two Dakotas upon which we can proceed with a great deal of confidence about the artesian waters. There has been sufficient study of the geology and sufficient experimentation to make a basis from which to start.

Senator CASEY. The confidence of the country with regard to the James River Valley itself is established; but the notion exists in the minds of the people that when you have left the particular formation which makes that valley (of which they know nothing, but which they suppose is the formation inclosing the valley) they will not be able to get water. They have not the courage to expend money for wells there. If the Geological Survey will ascertain that the basin is not confined to that particular valley, experiments will go on by the people in all directions, but they must have some one thing to give them that courage.

The CHAIRMAN. Suppose that, taking the places that are known, experimental wells were sunk outside, where the probabilities are great, but where people are not willing to make the experiment, the Government money would not be wasted, would it?

Director POWELL. Some would be wasted and some not.

The CHAIRMAN. If where you succeeded and gave courage then private enterprise would take hold of it; even if you did waste some money the information would be valuable. By sinking the well the formation would be discovered as you went down. What would be the average cost of these wells?

Senator MOODY. The well at Redfield, complete, 1,050 feet in depth, cost $3,100.

The CHAIRMAN. What did the well at Huron cost?

Senator MOODY. That will cost more, although it is not quite so deep.

Senator CASEY. That well at Jamestown cost $7,000. But there is nobody who knows just what a well is going to cost.

The CHAIRMAN. I should like to get at a general average, to see how much money is necessary to accomplish any useful purpose.

Senator MOODY. Mr. Holt, whom you met at Huron, I suppose, gave the matter a great deal of attention, from the fact that he has had the management of a farm mortgage company there. He told me that they had received an offer from a responsible company to sink thirty-five wells in that region of country for $35,000.

The CHAIRMAN. What would be the average depth of those wells?

Senator MOODY. The average depth would be about 800 feet.

The CHAIRMAN. If they went to the higher lands they would have to dig deeper wells?

Senator CASEY. That would be relatively more expensive. I saw Mr. Holt and other people at Huron quite late in the season, and the people on the ground were quite doubtful as to whether it could be done at that price. So that I think that you will need to reckon on these wells costing $5,000 each, taking the average of the country up and down.

Senator MOODY. Possibly, if you reckon on the divide, that may be so.

The CHAIRMAN. Major Powell has got $250,000 for the plains.

Director POWELL. Yes; if the work is to proceed on the theory that the basins are to be discovered by the boring of wells then the appropriation should be larger. If you want immediate results and want to proceed on the theory that the investigation must be made by experimentation, the appropriation should be larger and it should be expected that much of it would be wasted.

Senator CASEY. That could not be avoided.

Director POWELL. With that understanding we can go ahead experimenting.

Senator MOODY. If every experiment was to be a success we would not want you to make any experiment. We would make it ourselves. It is for the very purpose of determining absolutely that it is no longer an experiment that we want this done.

The CHAIRMAN. The situation out there is very pressing.

Director POWELL. If you will give me sufficient money, I can, within one year, put a corps of geologists and engineers boring on the plains, but it must be understood that much would be wasted, and when the work is finished not a very great supply for agricultural purposes will be given. The amount of water to be obtained from artesian wells is very small, but what there is will be of value.

Senator MOODY. That is what we want.

Senator CASEY. That is what we want, so far as North Dakota is concerned.

Director POWELL. Many of the wells bored would be failures; others would be successes. A double corps would be needed—a corps of engineers and a corps of geologists.

The CHAIRMAN. There is a vast population there now that are suffering, and the Government can afford to give them courage, if it is possible to do so. If it could relieve them at once and stop their sufferings it would be a great blessing to that country, for it is really suffering. There are 600,000 people there and they have lost their cour-

age. They want immediate knowledge in order to give them courage. They are a vigorous and active people and only want encouragement.

Senator CASEY. They want the knowledge that the Government is taking an interest in this matter. They want it in a palpable form.

Senator MOODY. Of course we know the existence of this rim-rock. I believe you call it Sioux quartzite?

Director POWELL. Yes.

Senator MOODY. It is a formation by itself. Of course we know there is a little out-crop of that quartzite on the Jim River, which is not very material, and there is nothing of it as you go west. The limit of this artesian basin, west, has never been found. In other words, it has never been a total failure to find the artesian basin. So we think, or at least we hope, that the proper investigation by scientific men—by the men that you will be able to send out—would supply sufficient facts, so that it would hardly be an experiment to dig a well.

The CHAIRMAN. How much of an examination would it be necessary to make to examine the Missouri River as to where it could be taken out, etc.?

Director POWELL. If any ordinary appropriation is made we will be able to do that next year.

The CHAIRMAN. I do not mean a general survey, but to ascertain the particulars?

Director POWELL. I understand. The single fact could be determined easily; it is a question of levels.

Senator MOODY. The situation of the country is such that after getting out of the influence of the Jim River, you have to take the water from the Missouri. You can not climb this ridge.

The CHAIRMAN. Oh, no. That is the thing we want investigated.

Senator CASEY. The bulk of the population of North Dakota lies east of what is known as the Coteaux.

The CHAIRMAN. Are you through with your general statement, Major Powell?

Director POWELL. Let me say just one word more, Mr. Chairman. If I beg for thorough work, which will not ultimately lead to disappointment, I want you to understand my motive in the matter. We can do work that will be valuable to the people at once, in some cases, but in many cases it would bring disappointment. If we are hurried in doing it, instead of doing it in a careful, scientific manner, many people will fail and will say "We have failed because we followed the recommendations that were given." We know of three artesian basins in the Dakotas: That on the Red River has been carefully surveyed. Its supply of water is limited; but it is in a region of country where irrigation is not necessary. Farther west there are two other basins, imperfectly known; one of them gives no evidence of being of great value; the other gives evidence of being one of the finest basins in the world and is worthy of the most thorough examination; and yet we can not hope for a great supply of water for irrigation from it. Water for towns, villages, gardens, ranches, and even for powers, may be obtained, and perhaps some small amount of water for farming purposes; but artesian waters are always limited, and excessive boring destroys them. The great basin of the Dakotas should be utilized to its fullest extent, but it must not be tapped beyond th.. or the whole thing will collapse. That has been the experience of many artesian basins; and it seems to me that it would be wise to direct the attention of the people more to the storage of storm waters. There are many portions of the Dakotas where this can be done advantageously and cheaply. Yet

do not wish to discourage the use of artesian waters to the utmost extent of the supply.

The principal supply of artesian waters in the two Dakotas is from the Dakota sandstone. All the great wells are found in it. We do not have to discover that sandstone; we know its extent throughout the country, but we do not know how much water it will yield. We do know that the supply is limited, that it can not be great; that it will be impossible to multiply wells indefinitely; and we do not know but that this source has been drawn upon nearly to its limit. Should I say to the people that this sandstone is found from north to south throughout the Dakotas and from the ninety-seventh meridian westward nearly to the Rocky Mountains, and that you can in most places find artesian waters in it—which is a fact—it would give the people courage to bore, and many wells would be immediately sunk, and the probabilities are that the supply would soon become exhausted and all existing wells destroyed. What we want to know is to what extent this source can be drawn upon and when the boring of wells into it must be stop. But what is still more important, we wish to discover whether there are any other water-bearing formations. All this can be determined in the most speedy and most economical manner by a geological survey based on topography and by an occasional experiment to verify the inferences of the geologist. The geologist is able to say that such and such rocks and such and such districts will not afford artesian waters. His first conclusions are therefore negative, excluding certain rocks and certain districts. Then he discovers other districts where the character of the rocks and the geological structure give probabilites that artesian waters may be found, and these probabilites must be tested by experimentation.

And finally, Mr. Chairman, I wish to be understood as expressing the opinion that when all the artesian waters are discovered and all utilized there will still not be a sufficient amount of water for the region of country of which we have been talking, extending along the plains from our northern to our southern boundary, greatly to affect the industries of agriculture. Artesian waters have always been and must be inadequate to meet the wants of irrigation, except here and there for gardens, orchards, vineyards, and for stock purposes. The great fields of Dakota can never be cultivated by artesian waters. To encourage the hope for success in this direction, on any scale adequate to the needs, is to give the people a false hope that will lead them to disaster. I know that the people see streams of water bursting out of the ground here and there, impelled high into the air, and in times of drought these are beautiful scenes. I know that they have reached the conclusion that there is a lake of water underground, and that rivers flow beneath their feet, and that they have but to tap these sources to receive an abundant supply. But I also know that these opinions are groundless; that the waters which they obtain are only those which percolate through porous sandstone from a long distance away, and that the supply is exceedingly limited. I know that the sandstone in which it is found is widely spread, but I dare not tell them of its extent lest they be tempted thereby to spend vast sums of money in vain, and reach still worse results by destroying the fountains already developed. It is my opinion that the resource is not exhausted, that some more wells can yet be successfully sunk into the Dakota sandstone, but to what extent it is safe to go on as they have begun I dare not say until a proper examination is made. I am not willing to deliberately face the facts before me and encourage the people as you desire.

Mr. Chairman, the discussion of this subject of artesian wells has come at the end of a long hearing, and little time has been given to it in view of its importance. I should be much pleased to be heard by the committee at greater length on the subject, and to prepare myself with maps and diagrams, that the question may be fully understood.

Is it wise to encourage the people to gamble for water with the dice loaded against them?

FOURTH DAY'S SESSION.

WASHINGTON, D. C., *January* 31, 1890.

The committee met. Present: Mr. Stewart, chairman; Mr. Plumb, Mr. Casey, Mr. Moody, and Mr. Reagan.

The CHAIRMAN. I will say to those who are here to-day that we have gone over generalities sufficiently. We have collected a vast amount of general material. What we want now is to hear from any person present who has practical ideas as to what can and ought to be done to facilitate irrigation; how it can be directly got at; what aid the Government can give most advantageously and with the least expense to make a profitable development of the arid regions. We would like to confine gentlemen to that. I would like to hear from two or three on that point. Mr. Nettleton is a practical man; and we will hear from him; also Mr. Hinton. (Addressing Mr. Hinton.) The committee would like to hear your views as to the practical methods of procedure desirable on the part of the Government to aid irrigation. We have already gone over a great deal of ground, and have collected the general history of the subject from the testimony taken throughout the country. Major Powell also has given us a good deal of the general history. We will, therefore, necessarily limit those whom we are to hear to-day to practical suggestions as to what ought to be done.

STATEMENT OF RICHARD J. HINTON, IRRIGATION ENGINEER, U. S. GEOLOGICAL SURVEY.

Mr. HINTON. In the work before us, Mr. Chairman, at present there seems to be two distinct points to be aimed at, for largely the running waters within the arid region are being daily and almost hourly consumed. By that I mean the streams and the waters in sight. The points to which I should direct then my attention would be: first, that we should aim at the conservation of the storm or surplus waters, which must necessarily be stored in the high altitudes of that region, and, secondly, the restoration for use in agriculture of the waters under the earth.

These two divisions at the present moment seem to me to be the essential purposes for which engineering efforts should be made. I suggest then that the great area lying east of the Rocky Mountains—the plains and foot-hills—from the 97th practically to the 101th degree of west longitude must come first, because of the great population that has gone in there, and of the large amount of struggle and of pecuniary effort that have been made by them; also, owing to the condition in which they are being constantly placed by reason of the insecurity or uncertainty of the water supply. These severe conditions arise not so

much by the deficiency of the water supply—taking the years through—as by its unequal and unsuitable division. What we call the great plains region, then, has for the work of reclamation to be first considered, upon the ground that the largest part of the population to be benefited by irrigation are to be found therein.

The problems involved in that fact are, of course, two-fold, as in the whole field: These are the storage of the surplus waters in the Rocky Mountains proper and in the valleys of the streams flowing there, and the obtaining of an adequate knowledge of the waters within the earth, so as to make plans and lay out the best methods for their economic use in the near future.

In the two Dakotas, our journey last summer, and the evidence that has been taken by the committee, show the most remarkable artesian water-belt, I think, known in the history of the world. The statistics are very limited thus far as to its definite limits, but I have obtained a list of about forty of what I would call town-wells, having depths from 1,600 to 1,800 feet and a pressure of from 80 to 220 pounds to the square inch. These are within a comparatively limited area, which, with perhaps two or three exceptions in the James Valley, would be below a level that would allow them to be supplied from the seepage or percolation of the Missouri River. I do not say that they are so supplied, because no one can tell that at present, but the levels are such and the geological indications, so far as known, are such as to give reasonable ground for the belief that some of those wells may be so supplied.

Senator CASEY. From the Missouri River?

Mr. HINTON. From the seepage and percolation of the Missouri River. From my observation, covering many years, and of late years very closely applied, I am convinced that we know very little as to the practical extent of percolation or loss, the underflow some call it, from the waters of the great rivers flowing across the plains, and through the arid region generally. That is the field of observation that we have to develop. I believe that under this so-called underflow is in a large degree the source of a very great many of the springs and of the wells that we find in those regions.

Senator CASEY. Of the artesian wells, also, do you think?

Mr. HINTON. Of the artesian wells, also. I could not put that forward as anything more than a reasonable suggestion, because there has yet been no investigations of a character sufficient to warrant anybody in positively stating such a theory.

It has been said that we need a topographical survey for experimental work in that region. Against the able and distinguished gentleman who assumes that, I hate to place myself as hostile, but I believe that the experience of all engineers testifies that it is a fact that topography can not indicate clearly or definitely where any artesian or other water may be found. Geology certainly can help in that direction and it certainly will help. The Dakota basin seems to be geologically delimited, so that its eastern rim is well defined; its general formation is understood, and if there can be an appropriation for the purpose of definite experiment in regard, first, to the artesian water supply, its area and sources, and second, to the gauging of the great stream that runs through the Dakotas that is the Missouri River, so that we may know definitely the amount of water, of the volume, etc., that flows through its channel at any given time, we shall have accomplished a piece of work that, well done, will be done for all time, and does not depend upon a topographical survey or even upon a more definite geological examination.

If I am asked to recommend the way, I beg to suggest a considerable appropriation for these definite purposes: first, of ascertaining the character, through the boring of experimental wells, by the river gauging suggested, and by the location of tanks or small reservoirs, of the water supplies of the two Dakotas; secondly, to place the States of Kansas and Nebraska, with their Arkansas and the Platte River Valleys, in another district, find out the same class of facts therein, and in addition investigate the best manner of recovering the great body of water which sinks into the earth—the water which flowing from the mountains spreads through the broad channels I have named, and finally sinks into and is extensively retained by the stratum of gravel and sand, immediately below the soil.

There are artesian wells in northern and central Nebraska. Reaching over into northern Kansas, in the Republican Basin, will be found a large body of water lying near the surface, which can be made of great agricultural value, at little expense, by experimental work and development.

When we come to southern Kansas, we find that there has already been some work done in the way of ascertaining the value of the seepage or percolation of the Arkansas as it flows eastward. At Dodge City, though the work has been temporarily stopped by the winter storms, they have already run some 20 miles of tunnel or drift. The average fall of the Arkansas River from the mountains is about 7 feet to the mile. This insures the possibility of putting in levels for the purpose of obtaining that under-supply and distributing it over the land at no great expense.

Senator CASEY. Point out on the map the regions to which you refer, as you go on.

Mr. HINTON. This is the Arkansas River [indicating], here is Dodge City. At Dodge City they are running a tunnel in westward. The average fall from the mountains, then, is at least 7 feet per mile. The project is to take it out on either side by reservoirs and laterals, and distribute it on the land. In the counties to the south, there is a considerable artesian well region. There are a number of artesian wells in Meade County and elsewhere in that section; of this, the committee has taken evidence.

In eastern New Mexico there is an extensive region of large springs, showing the existence of water under ground that comes with great force to the surface, We find when we come to northern Texas, and to what is known as the Staked Plains and the Panhandle region of that State, that there are in existence to-day a great body of wells. Some are artesian in character, but there are many that flow so near to the surface and with such force that it is evident that if these wells were sunk deeper they would have the artesian quality; they would strike that stream. It is a general belief there, among both engineers and practical observers, that the water under the Staked Plains, the water from which these wells are supplied, has the character of a flowing stream. Some experiments have been made in the neighborhood of Marienfelt, Odessa, and Midland, on the Texas Pacific Railroad, which seem to indicate the correctness of that theory. The altitude lowers abruptly, and the land is of a totally different character. Beyond the westerly limit of the Staked Plains the land is all of a distinctively arid character, as arid as Nevada or Arizona. It has no precipitation exceeding 8 to 11 inches of fall per annum. But throughout northwestern Texas there is unquestionably a large underground water supply. The springs

which come to the surface, the evidence of the wells upon Staked Plains and in the Panhandle region, indicate this. Indeed, the testimony all goes to show that there is a supply sufficient if it could be brought to the surface to answer the purposes, by small storage, of almost that entire region. The rain-fall will average 20 inches per annum.

The CHAIRMAN. You do not mean by that statement to say that it would be sufficient to irrigate all the land, do you?

Mr. HINTON. No; not all of Texas west of the 97th meridian. By no means. Of course the valleys of the Colorado and of the Pecos Rivers must largely be a surface-irrigation region, supplied by those streams. But still a large portion of the area can be supplied by a small storage system that may be made by conserving the local rain-fall from the surplus of the wells, by their storage, and by that of seepage or drainage water also. My own judgment is that on these great plains running through, east to west, between 97 and 103 degrees, in the main, small storage rather than great works will for a long period of time to come be the reasonable and safe means of supply for the people living therein.

Looking at the Great Plains region practically, and as a matter of legislative recommendation, I should say that this Government may reasonably and properly expend sufficient money to find out the water supplies thereof; to ascertain how they can be most economically conserved and used; in short, to learn definitely to what extent these plains may be made permanently available for agriculture, or whether, in fact, they must be in large part retained only for pastoral purposes. This knowledge may be obtained, rapidly and with sufficient accuracy, without the delays necessarily incidental to a full topographical survey, or even of a minute geological survey. The pioneers will go onto these lands. They should have accessible the information requisite to their proper direction.

Of course, I beg leave to say, that it is the business of legislators to see that a proper topographical and proper geological survey shall be carried on, but I do not think the Irrigation Survey is necessarily dependent on their progress. On the contrary, I suggest, with all deference to abler men than myself who express a contrary opinion, that the delays incident to their completion will result in a positive injury to the irrigation work. There are competent engineers in the Survey, and there are facts sufficiently known as a basis for their action, so that it would be possible to commence at once the work of investigation for experimental artesian wells in certain directions; the work of developing the quality and the character of the percolation of the great valleys I have named, the Arkansas, the Platte and others, the flow and character and volume of the Missouri, as it runs through these regions. All this is absolutely necessary. Engineers and geologists may arrive rapidly at proper conclusions. The railroad surveys made across the plains will give all the needed altitudes. A series of field reconnaissances can be vigorously pushed. All the preliminary facts can be arrived at in a proper manner some time before this Congress adjourns, and at a day early enough to enable it to have some definite information before it on which to base any other action that it might deem desirable. I want to add that whatever money expended experimentally on these lines will not need to be continued. A topographic survey, or rather a series of topographic maps, is not a precedent condition.

The CHAIRMAN. Your attention has also been called to Arizona. There are a large number of petitions from there for experiments such as you suggest.

Mr. HINTON. Arizona is a region over which I have traveled and observed almost as much, in days past, as I have in Kansas and the central region. In southern Arizona there are areas of underground supply that can be developed. The Santa CruzRiver, for example, flows under ground to Maricopa, in the Gila Valley. It runs into the Gila River near that point. The Santa Cruz River rises a few miles below the southern line of the United States, in Mexico. It runs almost directly north to Tucson. Nine miles beyond Tucson it is lost under ground, and then, for some 87 miles it flows under ground, until it enters the Gila and helps to swell that river. The valley of the Santa Cruz contains about 1,140,000 acres, a very large proportion of which, if there were water for it, could actually be brought under the most efficient horticultural use. It is a region admirably adapted for fruit. At the Mission of Tumacacori, and at Tubac, Calabasas and other places, there are the remains of fruit gardens that the missionaries planted and used. I have seen, in years past, all the semi-tropical fruits growing on farms that were maintained there against the Apaches. The Santa Cruz River should be taken out, as near its source as possible, and distributed by means of high-line canals.

The land is very fertile. The river has a great drainage area at its head. It is fed by several very important small streams on both sides, and if it were taken out and placed in a new channel, and distributed over the valley, the entire region at and below Calabasas could, I believe, for some 10 or 12 miles wide and 150 miles long, be made a perfect garden. We used to fancy in years gone by, in traveling over the Cienega, north of Tucson, that we could hear the waters running under ground. I do not know whether that was a correct inference or not. Eastward, and lying beyond the Dragoon Mountains, will be found the San Simon Valley, or plain, known in the olden days as the principal route southward of the Apaches. You can get water in the San Simon and Sulphur Valleys anywhere at from 8 to 40 feet below the surface. All through, in this low table-land, you will find wet places—the Mexicans call them cienegas. There are a number of ranches in that valley now supplied by such waters, from either wells or tanks and ponds. The San Pedro River also, between the San Simon and the Santa Cruz, rises in Mexico, as the Santa Cruz does, and can be, by storage near its head, made of much greater service than is now the case. Upon the plateau on which Tombstone is situated they have some artesian water, and I understand there are two flowing wells at that place.

Crossing into New Mexico, over the Chiricahua mountains, and beyond the eastern foot-hills of that range, you reach Deming and the table-land around it. Water has been found there from within 25 to 40 feet of the surface. It is an important railroad junction. It is so near that slight pumping brings it to the surface, and makes it valuable for the small irrigation, for fruit and gardens, that is going on in that region.

From what I can learn in relation to it, it would be possible to develop the whole well or artesian water-power there, and create a small storage system which would bring a large proportion of that mesa, or bench land, under cultivation for grass and root crops, as well as for fruit. Through this region and up to the lower foot-hills, water can almost always be found a short distance from the surface. Most of these little valleys of that region could be reclaimed by the use of small storage.

The CHAIRMAN. What have you to say as to Salt River and the Gila, and their valleys?

Mr. HINTON. The Salt River and the Gila are necessarily to be developed by large systems of irrigation. I do not believe that the Government of the United States will have to expend any large sums of money in the direction of assisting Arizona or the capitalists who may interest themselves in the reclamation of those two valleys. When I first visited Salt River, years ago, there was considerable land in the hands of small farmers with little ditches. The same thing can still be seen in the Mesilla and the Rio Grande Valley. Within a few years, as the evidence taken last summer will show, the Salt River Valley has passed under the control of a large corporation. The supply is better managed and of a much better character. If their propositions are carried out it will still further increase. There is probably no region, even in California or any other State within our borders, that presents a larger future as a horticultural or fruit-raising region than the valley of the Salt River and the valley of the Gila. On the Gila there are points where storage reservoirs should be maintained—at the buttes, near Florence, and above. Large irrigation systems are always desirable.

This region through here is a cañon region [indicating on the map]. It is not itself of much use for agriculture or even for pasture, but it is of great service as a source of water supply. In this region [indicating] the irrigation would be accomplished largely by local storage, some of which will be quite extensive, as at Walnut Creek; but it will be what in the future will be known as a secondary system. It will not be the high altitude storage system.

In regard to high altitude work we must bear in mind that what we now really know of the precipitation over the whole of this region relates more to the valleys and the table-land than to any other part. All the meteorological or weather service reports that we have had have been simply for the purposes of local trade and traffic. We have had no system of observations of a definite and distinct character in regard to the mountain ranges. The rain chart presented in the last census by Mr. Gannett, and of which I have a copy here, and which has been improved by later observations, shows that the only record we have of rain-fall definitely from the ninety-eighth degree to the Pacific Ocean will range, going from the east to the west, from 20 inches down to 8 and 9 in the basin, and up again to 18 and 20 or 24 on the Pacific coast. At some points it will fall as low as 3, 4 and 5 inches. This is the record at Yuma, in the Colorado Desert, at Mojave and elsewhere. We know as a matter of fact, though not from a recorded series of observations, that the rain-fall and snow precipitation on the mountains is as from 3 to 5 inches in excess of what it is in the valleys below. The average snow-fall on the Sierras will be from 60 to 70 feet of loose snow, giving us on the basis of 11 inches of snow to 1 of water from 5 to 6 cubic feet of water. All, or nearly all, of this water runs to waste. At least 90 per cent. of it passes away in evaporation, or largely in the ground. The largest portion disappears below.

The first great feature of an irrigation survey proper will be the conservation of these storm-water supplies. I take it for granted that it is not necessary to accompany a survey for that purpose by an attempt at an accurate topographical survey of the lay of the land. I have never seen or heard of any country in which a topographic survey has been considered a condition either precedent or subsequent to successful irrigation. The chief objects, then, of a United States irrigation survey to my mind are, first, to delimit, so as to be known of all men, the drainage areas; secondly, to define the available reservoir sites within those areas; and thirdly, to indicate the channels by which they can be most economically distributed when made.

So far as the Government of the United States is concerned, it being definitely understood that there is no work of construction to be undertaken, the object that it should have in the establishment of an irrigation survey is to achieve those definite and distinct points, the delimitation of the drainage areas, the definition of the reservoir sites, and the indication on the maps, the simplest and clearest that can be made, of the leading, most economical, and safest methods of storing and subsequently distributing the waters that are to be conserved.

The work I have indicated as that which in my judgment should be done east of the mountains would be largely in the way of experiment. Some of it might fail; other portions of it would, I believe, succeed. I do not know positively; no one does; but I believe so. But, when the wells are once sunk so that we have found the definite basis of supply; when the rivers and streams are gauged; when we have examined into the question of the value of the percolation of the great streams like the Arkansas and the Platte, the money expended on that would have settled the questions at issue. The encouragement which will be thus given to industry and effort will be quite sufficient to induce private capital to go in with them. Behind that and beyond it the work of the great storage basins must go on. Each drainage basin is supplied in the main only by its own local precipitation. We do not get any more water practically than falls upon it. In, therefore, developing such a region as the Arkansas Valley, while we do not necessarily now have to establish, and might not this year or the next have to establish, the high storage basins, we must expect to see them developed and completed finally in order to insure continuous security and safety to the entire valley.

First, then, I would take the Arkansas Valley as one practical fact. I would take the valley of the Rio Grande, which is in peril, as another. Both of them, owing to the great snow-storms of the passing winter, may be very well situated next summer, yet all the time they are in peril. This is owing to the use of the water in Colorado, the State wherein they both rise. The proper use of the Colorado use is water. It is necessary to develop the facts indicated by the Director of the Geological Survey. I believe they are facts. In the Rio Grande Valley there will be found to be a series of great storage and drainage basins, each portion of which can be served by its own high altitude precipitation by the snow and storm waters stored in the mountains that mark the drainage rims and outline these great basins.

Utah comes next in my judgment. The people of that Territory have developed the primary forms of irrigation in a manner and to an extent unknown elsewhere in the country, but they have reached pretty nearly the limit of their capacity in that direction. And with the recurring arid or dry seasons they are always in danger of losing their prosperity through the loss of crops. They have 600,000 acres of land under water, and usually irrigate that much. Last year, as the testimony before your committe shows, not more than 350,000 or 400,000 acres of that land were in cultivation. Utah needs deliberate and definite work in regard to defining and delimiting, as I have said, the drainage areas and their reservoir sites with a view to the encouragement and support of those people. It will also need some work in the development of the underground supply, because in the basin of Utah Lake and elsewhere to a limited extent there is an underground supply produced by the drainage of those great waters, and the United States might profitably spend a little money in testing the capacity and extent of the areas thereof.

The same is true of Nevada. Nevada, perhaps the chairman will permit me to say, is looked upon as rather the lost sheep of the American Union; as having very little capacity for anything now except the possible discovery in years to come of a new bonanza. I do not hold that opinion, and I have passed much time traveling through Nevada in the last fifteen or twenty years, and have studied it closely, and I believe it is possible to make Nevada, by a comparatively moderate expenditure, by means of the reclamation of its arid lands from water supplies that are in sight, a State that will support a population of at least a million of people in the comfort which irrigation produces to the community wherein it is practiced. I should like to say here that farming by irrigation produces a more comfortable life, more prosperity, and, so far as my observation goes (and it extends from America to Egypt and from there to China), it produces more food supplies, more sustenance from the land, and brings more comfort, prosperity, and certainty to those who work by it than any other system of farming does. It makes the production of food almost as certain as the weaving of cloth.

I have gathered a few items regarding Nevada which will take but a moment or two to state, because there are some problems involved there in the question of reclamation that need consideration.

The area of that State is 71,737,600 acres, of which the water area is but 1,081,600 acres. The timber is estimated to cover 2,600,000 acres; the pastural area is estimated to be 30,000,000 acres, the mineral area 15,000,000 acres; the desert and saline deposit, 3,656,000 acres, and the agricultural area is placed at 20,000,000 acres. That is the area to be reclaimed, if water can be obtained.

The State board of reclamation appointed to consider the question of irrigation therein, in the report embodied in your testimony, presents a series of statements by counties, which will show an area of 17,981,000 acres as possible for reclamation, of which area 2,198,000 acres can, in their judgment, be reclaimed by wells and springs that are known to exist. In Esmeralda County, in the southwest, there is an area considered to be reclaimable, and also in White Pine and in Nye County, in the southern and eastern part of the State. There are sixty-five artesian wells in Nevada. The average altitude of the State is considerably over 4,000 feet above the sea-level. It is a mountain bowl, surrounded by high ranges, and the fact that there is found even that limited number of artesian wells would indicate the necessity at least of examining into the character of the drainage or underground water supplies. There are a large number of important springs.

The trouble with Nevada is, in the main, that the drainage area that will most surely supply the water needed for reclamation is found largely within the limits of other States and Territories. In the north, the rivers head up in the northerly and northwesterly territories. On the west, the easterly slopes of the Sierras are unquestionably part of the drainage area of Nevada. I am not speaking of political lines, but of the natural features. The great lakes that lie upon the Sierra Nevada are mainly upon the eastern slope of those mountains and the waters naturally and properly belong to the people of Nevada. Take Lake Tahoe, 78 square miles of its surface (that is, two-fifths), are within the lines of the State of Nevada; the remainder is within the lines of the State of California. Lake Tahoe is ranked with navigable waters and belongs then to the Federal Government. It is all on the eastern side of the mountain. The ranges rise from 3,000 to 6,000 feet above it. Lake Tahoe has a drainage area of at least 1,200 square miles; the

valley of the Truckee has a large drainage area. From Lake Donner and the other lakes that are known along that range water can be obtained. Lake Donner has been surveyed and its boundaries meandered. It is now reserved for irrigation purposes. Sufficient water can be obtained for western Nevada without the loss of a single cubic inch to California. By the storage of water in the mountain lakes alone enough can be obtained to reclaim from 1,000,000 to 3,000,000 acres of land. Even if it be but 1,000,000 acres it will amply repay all its cost and double at once the values of the State.

That land is worth nothing, or very little more than nothing now. It would be worth from $15 to $30 an acre if it were watered. That would make as prosperous a community as could be formed within the borders of the Union. Nevada was born during the war, and by her mines hundreds of millions in precious metals have been added to the general wealth of the country. The larger proportion of those who have benefited by that development have left Nevada to struggle through the poverty and indifference that are now surrounding her people. I think it is within the range of legislative action to consider whether this child of the mountain and of the war can not be benefited by some special work and special appropriation to carry on that work. I hold that Nevada stands first with New Mexico and the Dakotas, with Kansas and Utah, as among the earliest regions to be considered.

The committee will understand that I am an officer of the Geological Survey, and that I am not placing myself—not intending to, at any rate—in direct opposition to the Director in any of my suggestions. I design only to do my duty to those on whom falls the responsibility of legislation. I am obeying orders to me imperative. My observations and my knowledge then, such as they are, lead me very strongly to the conviction that a topographical survey, a platting of the entire arid region upon the scale of 4 or 20 feet to the square mile, is absolutely unnecessary for the carrying on of an irrigation survey such as I have understood Congress to have designed in the making of its appropriations. I have seen irrigation practised from Utah to Egypt and from California to China, and I have studied its entire history, but I have never yet seen or learned of a region in which a topographical survey was a condition precedent or even subsequent, so far as success was concerned.

I believe the Irrigation Survey should take on very largely the feature of a great reconnaissance, conducted by civil engineers competent for that purpose. I have in my own mind framed a little idea as to what it might possibly cost to put such a work for the next year under way. Of course, I do this without having that definite knowledge of the administrative needs which come only from the direction of a large office and of the handling of the expenditures thereof.

I have placed the total appropriation at $750,000, of which I should expend, or should indicate the expenditure of, $350,000 for the development of the underground water supply—the wells and the river underflows in the region lying east of the mountain. The other $400,000 I would expend in as rapid and as complete a series of surveys as possible—surveys or reconnaissances by proper engineers competent for that purpose. I think that ten or twelve such parties could be put into the field and practically a large part of the work of delimiting and defining could be done. The need of rapid work is shown by the fact that seven-tenths of the arable portions of our remaining public domain is now found within the arid region.

The Irrigation Survey divides into three parts, as a method of admin-

istration, in my mind: First, the civil engineers, whose work it is to obtain the information; second, the hydrographic engineers, whose work is of a delicate and important character, in the ascertaining of the water supplies, their extent, their volume, etc.; and third, the creation practically of a new division, which has never yet, in any large sense, been attempted. We want a small corps of trained observers in climatology. We ought to have a small number of stations at least, in the highest altitudes in which they could be placed with safety to those who are to work therein. We ought also to have an appropriation large enough—it would not be a great amount of the total—to encourage the taking of volunteer observations in mining and lumber camps and in other places where labor and human habitation go on in those high altitudes, and we should have some persons to superintend and to gather and obtain this knowledge. It has been suggested to me by a gentleman who has studied this question and is familiar with the work that $10,000 or $12,000 expended properly in that direction would be as beneficial as anything that could possibly be done.

This is not simply weather service observation. Weather service observation is a minor division really of the greater service suggested. What is needed is the study of climate in its largest aspects; in these regions and under those circumstances that will bring the most return. First, then, I say, that an irrigation office wants a competent civil engineer and staff; second, it wants a competent, but small staff of hydrographers, and third, it wants a small staff of students or observers in climatology.

Senator REAGAN. Would you not extend that to the valleys as well as to the mountains?

Mr. HINTON. I would, of course; but the valley observations can be properly carried on by the Signal Service, now in existence, and so that there could be perfect co-operation. A very large proportion of the lower altitude work can be carried on by a little extension of the present weather service machinery, but the law and appropriations for the present machinery do not embrace that of which I am speaking—they are not intended to embrace it—they are not designed to cover it, and Signal Service men are not properly or particularly well trained to do it. I would simply supplement their work and bring the two into harmony. That is why I say it does not require a very large sum of money.

In carrying out the work of an irrigation survey during the present year, at least, it is not necessary to press this class of work in the regions where the population, so far as is known does not immediately demand it. I should aim to carry that work out in the regions where it is mostly to be required for immediate necessities. I have indicated in part what those are. At the same time I believe it will be possible within three or four years to close up entirely the field-work of the irrigation survey proper. If I am not mistaken the topographical survey, which is doubtless a necessity for the future, which every great country will carry on, and should carry on, is a question of time, so that if the irrigation work is to depend on the progress of the topographical survey according to areas covered as presented here it would take some twenty years or more to complete it at the present rate of expenditure. It would take less than that at a larger rate of expenditure, but it would take not less than $8,500,000 or $9,000,000 to complete in conjunction with the irrigation work a topographical survey of the region west of the one hundredth meridian of longitude. It is estimated to cost $5 per square mile, and I have heard so competent an engineer as

the able officer in charge of the irrigation survey declare that he can do the work needed for 1 per cent. of the lowest cost estimated for a complete topographical survey.

I think, then, that this topographical work may well wait on the progress of the population and the growth of wealth. I do not believe either that it can now be done with that sufficient accuracy by the means now in hand that will warrant the attempt. The makers of maps who have had the handling of the topographical maps made by Wheeler and Hayden, and others in the West heretofore, find the grossest errors. At various times I have been told of localities in which a difference of as much as 1,000 feet has been found. The topographical survey that is now being carried on is certainly in the largest sense a much more accurate attempt at that work than has ever been attempted before in the country. But it can wait, as I suggest, upon the progress of population.

I want to call attention, if I may be allowed to do so, to the necessity of action on the part of Congress at this present session with regard to the boundary matter and the international dam at El Paso. It was once my fortune to live in that city for twelve months. At the time I thought it was an ill fortune, but I have got over that idea since. I have traveled through northern Mexico a good deal and have studied the condition of the people there, and have been up and down that valley and I know something of the circumstances that surround it.

Unless some action is taken to definitely determine the boundary-lines between the Republic of Mexico and that of the United States at the point where they come together at El Paso and below it is quite certain that there will be continued trouble, disorder, and want of peace from year to year. It is not a question primarily of irrigation; it is a question of international obligation. Under the treaties of the United States the people of Mexico are entitled to certain rights. Under the circumstances which surround the flow of the water in the Rio Grande they are deprived at present of those rights, and they are deprived not by their own action, but by the action of that portion of the American people who live within the upper boundaries of the Rio Grande. It is not, of course, an intentionally hostile action, but its effect is the same. It is therefore necessary that action should be taken. There have been, as you are well aware, surveys made and plans devised which are admirably adapted for the establishment of an international dam and reservoir at El Paso. In a little publication which I have received this morning (I think it has not been made a matter of record even) Major Mills estimates the total cost of the dam—the purchase of the land and the railroad removals that would be required——

The CHAIRMAN. I think Major Powell gave those figures.

Mr. HINTON. The total amount is $1,007,599. I did not know whether they had been given.

So far as the survey is concerned the work has progressed. I take the liberty of urging that such legislation be had as will bring about at an early day the appointment of an international commission for the purpose of settling that difficulty. I shall be glad to answer any questions which the committee may ask.

Senator CASEY. In the matter of experiments, in my State, for instance, how many wells would you guess would be required to make that test as to the extent of the irrigation basin?

Mr. HINTON. Colonel Nettleton, who is the engineer of the Rocky Mountain portion of this present survey, is here with us, and I think

he can give you, because he is an experienced well-man, a better hypothetical statement than I can.

Mr. NETTLETON. I never was in Dakota in my life.

Senator CASEY. Major Hinton has made certain estimates of the proper amount to be expended for work of that kind. There should be some basis for those estimates. Of course work in our country would depend entirely on the number of wells necessary to be put down. As he has named an amount that would be proper for the work, I suppose he has given some thought to that.

Mr. HINTON. I would myself suggest this: that a special appropriation be considered as one for the purpose of putting it into the hands of the proper persons and making a reasonable inquiry into all the facts, and proceeding thereon, at the earliest moment. I have the names of some forty wells.

Senator CASEY. Many in South Dakota?

Mr. HINTON. Yes. But there is hardly a single fact upon which we can predicate any definite statement.

Senator CASEY. Do you know the depths of those wells?

Mr. HINTON. Yes; we have the records, and can give the widths across. We know the geological formation largely, and can obtain very much of that information. Some of it can be obtained here without going to Dakota.

STATEMENT OF E. S. NETTLETON, SUPERVISING ENGINEER.

The CHAIRMAN. Please state to the committee your occupation, and whether, in your profession, you have had experience with the work of irrigation; if so, how long.

Mr. NETTLETON. I have been for forty-five years in the profession of civil engineering—twenty years in irrigation and mountain engineering in the West, mainly in Colorado. For the last twenty years I have been connected with the Department of Irrigation, mainly in Colorado. I have been connected principally with large corporations, and for four years I was State engineer in Colorado, creating and organizing the department of water engineering. I have also assisted in draughting our State laws relating to irrigation. I joined the United States Irrigation Survey last May, as supervising engineer, for the eastern half of the arid country.

The CHAIRMAN. I wish particularly to inquire, from your experience and knowledge of the country, what is the best and cheapest way, from an engineering point of view, to commence a survey sufficient for the uses of agriculture by irrigation, also how it can be most speedily prosecuted and with least expense—in fact, what ought to be done to secure such a survey and what is necessary to accompany it.

Mr. NETTLETON. As I understand the law upon which the appropriations are made for this purpose, it seems to me that the whole of this work can be accomplished by what I would call an irrigation engineering survey—including sufficient topographical work and sufficient hydrographical work. It seems to me that the whole can be done under one head or in one department——

The CHAIRMAN. Would you have the engineers do the necessary topographical work as they proceeded?

Mr. NETTLETON. Simply do what topographical surveying is necessary—not surveying any pasture lands or mining sites outside. The hydrographic work is a part of irrigation engineering, and that can be

done under the same management. So I do not see any necessity for separating or making three divisions, all working separately from each other in the field, none knowing the work of the others until the next year, perhaps longer.

It is a fact that the engineering work is dependent largely on the hydrographic work. In many localities we find a large number of reservoirs and it is a question whether there are not more reservoirs than water. It is only by the hydrographic work that we can determine whether the basin is too large. The hydrographic and the topographic work should go together.

The CHAIRMAN. Suppose you should reserve temporarily more reservoirs than are required, and you found you did not have water sufficient, you could only utilize those that you had at first water enough for; the others could remain reserved, and if you found, by experience, that there was a deficiency of water supply, and you got people into the country, then you could make other reservoirs and increase your supply. It would not be necessary to know the full extent of the rain-fall, etc., before making the reservation.

Mr. NETTLETON. I was basing my suggestion on doing the work in the quickest time possible and with the least money.

The CHAIRMAN. That is what I want to get at—the Government work that should be done to enable the people to carry out the rest.

Mr. NETTLETON. In the arid country the first thing would be the finding of reservoir sites—ascertaining their extent and estimating the capacity of the dam to impound the water. I believe it is in the law that we are obliged to make estimates of the cost. That necessitates the making of a thorough survey.

The CHAIRMAN. Of the reservoir sites?

Mr. NETTLETON. Yes; also of their capacity. I think it is also necessary to have the drainage matters established. Then it is necessary to run the preliminary lines of high-line canals.

The CHAIRMAN. You would not make a working survey, but run the general lines and leave monuments.

Mr. NETTLETON. I am not certain whether the law does not require the cost of these irrigation canals, and if it does, it needs something more than a rough high-line to determine the cost of an irrigation canal.

The CHAIRMAN. If they had a reservoir site set aside and the high-line run, the people then could understand the situation.

Mr. NETTLETON. Yes.

The CHAIRMAN. Might not the estimates of cost on the ditches be postponed and that work done afterward?

Mr. NETTLETON. Yes; I think that if either was dropped out the estimates of the cost of canals might be.

The CHAIRMAN. Might be postponed?

Mr. NETTLETON. Yes; I think it would be well to make surveys of the reservoirs so as to make pretty close estimates of the cost.

The CHAIRMAN. And of the high-line ditch?

Mr. NETTLETON. Yes.

The CHAIRMAN. Then the people would go into it and make their own estimates of the cost of the other parts?

Mr. NETTLETON. Certainly.

The CHAIRMAN. What expenditure, if you have estimated it, would be necessary per annum, to prosecute this work with vigor or as fast as it is required?

Mr. NETTLETON. Covering the whole arid country do you mean?

The CHAIRMAN. Yes, leaving out the experiments for wells, because that is temporary, and we have to estimate that separately. I mean for a survey for the arid country, locating reservoirs and indicating the lines of ditches—how much per annum would be necessary to carry on that work?

Mr. NETTLETON. That will depend on the time given to complete the work. The best and most economical way would be to extend it through a series of years—five, eight, or ten years—beginning in a small way with small appropriations and gradually increasing the appropriations as we get a better knowledge of what to do. This is all new work to all of us, and my idea would be that commencing in a smaller way and feeling our way along. would be better than to expend a large amount at first, part of which might be useless.

The CHAIRMAN. And you would use that money where the immediate demand is to arise, for use by the people?

Mr. NETTLETON. Everything else being equal, I would.

The CHAIRMAN. You would distribute it then in different localities, where they have population?

Senator PLUMB. That is, you would use the money in sections where people are already on the land rather than to entice them into new areas.

Mr. NETTLETON. Yes; I would try to develop that country where the people are—where it is possible to do so.

The CHAIRMAN. You would develop the inhabited localities?

Mr. NETTLETON. Yes; and if such development was not possible I would let the people know it.

The CHAIRMAN. I wish you would think it over carefully and particularly, then make a short statement in writing after you have looked over the field, and see where money is required. You have a knowledge of the country and how money can be expended to advantage. Give us a short paper on that. Take your time to do it.

Mr. NETTLETON. Do you wish me to name the localities and the amounts?

The CHAIRMAN. The amounts that would probably be required, yes.

Mr. NETTLETON. For one year?

The CHAIRMAN. For one year.

Mr. NETTLETON. I will do so.

STATEMENT OF EDWIN WILLITS, ASSISTANT SECRETARY OF AGRICULTURE.

The CHAIRMAN. The committee will be glad to hear any statement you may have to make that is of interest in regard to irrigation.

Mr. WILLITS. You sent to the Department of Agriculture last summer, Mr. Chairman, inquiring if we had any information on this subject. I will simply say that from the time I came to the Department irrigation was a matter of great interest to me. The first question I asked was, what was being done about it. I called upon the heads of divisions for information. They reported to me, and I had it in writing, but unfortunately it was on the general subject. Some of the gentlemen have come here this morning with information in writing. I do not know that we have anything to say in reference to the specific questions that you want answered.

I desire simply to emphasize the fact that the Department of Agriculture is highly interested in the subject. Some of its chiefs have

been across the country this year, but they have not, after all, specific knowledge. Their knowledge is general; therefore we can not answer many of the questions that you desire. I would like, however, to present the papers, and you can file them. We did not come here to make speeches, but to gather information for ourselves on the subject. I have nothing further to say except this: Colonel Hinton has referred to the absence of any study of climatology. I have seen the perfect weakness of all the information we have now on that subject. It is the great impending question in the Department of Agriculture.

The whole weather service has been confined to the mere skirmish of weather forecasts, etc., without studying the great broad question of climatology. I will emphasize what the colonel has said, that the subject is much broader than the question of ordinary rain-fall.

The CHAIRMAN. Is your Department doing anything in that line?

Mr. WILLITS. Nothing. To tell the truth we are waiting to see whether the weather service is to be transferred to us. If it is, one of the things that we shall do will be to organize it in that direction.

The CHAIRMAN. It seems to me that the weather service, if it is to extend all over the country, should be placed in your Department.

Mr. WILLITS. I have nothing to say on that subject, but I have simply said that if you do not transfer the weather service to us, and we should come at the next Congress and ask that you give us the power to study this question and its effect on vegetation and plant life, I hope you will do so. It is a great question. It is the most important question pending as a scientific and practical question. I have merely spoken of it because Colonel Hinton has referred to it.

Years ago I was very much interested in Colonel Hinton's Report on Irrigation. We had no information except what his report furnished to us. So I wrote a letter to you, asking that in some way or other that report might be incorporated into the report of this committee in some shape, modified as it might be. It is full of instruction generally.

That is all I have to say this morning, except to add that I would like to be permitted to have some papers filed.

I would also like to have Professor Fernow make a statement on the subject of forests. I should also like to have Doctor Merriam talk a little to the committee on ornithology and mammalogy—on the question of what effect irrigation will have on animal life and bird life—what new animals will probably be brought in or old ones driven out by irrigation. I do not ask that he be heard to-day, but at any time at your leisure.

Doctor Riley made a very important report on the influence of irrigation on vegetation and on Rocky Mountain life. I will present that also.

STATEMENT OF B. E. FERNOW, CHIEF OF THE FORESTRY DIVISION.

Mr. Chairman and gentlemen of the committee, you are discussing here a question of the building of a stable, and my subject has only to do with the feeding of the horse. That question you have overlooked. It is a question it seems to me of considerable importance, and, although apparently subsequent to the building of the stable, I think it will be desirable to take it into consideration, as it will become absolutely necessary to feed the horse when you have him.

I do not want to go into any discussion of the relation of the forests to water supply, but the practical question whether it has any influ-

ence or not has been called into doubt. The intelligent and practical man who does not wish to listen to arguments on the subject can go and see what other nations have done. France, Italy, Germany, Austria, all have done something for irrigation. The people of France have expended $50,000,000 for reforesting their country, for water supplies, and propose to expend $50,000,000 more. They expend it on a very small part of their territory—the southeastern mountains only. The effect of the work that they have done has shown that it was the proper work.

I call the attention of the committee to the fact that this work is being done, because propositions have been ventilated as to the desirable effect of getting rid of the forest area which the United States possesses. Italy, a small and poor country, has found out that 1,000,000 acres of their mountain districts must be reforested, and in their budget will appear $1,000,000 for their forests alone. Austria has found out that a portion of her territory must be reforested. Prussia, with a very good forestry department and area, expends $250,000 every year to rebuy the waste lands which must be reforested. All those countries are spending these large amounts of money through their forestry administration. France appropriates $5,000,000 a year for the forestry administration. Prussia appropriates $6,000,000 a year for the same purpose. I call attention to this only to show that these nations that are poor and must look after every penny, having no surplus to expend, expend this money because they deem it absolutely necessary. The United States has 70,000,000 acres of forest. They pay no attention to it. It is being devastated and burned up. That is the only point I was anxious to make before the committee.

But with regard to the feeding of the horse. I believe it is now well established that it is not so much a deficiency of rain-fall in the arid region or so much a deficiency of water supply as it is the difficulty as to the amount of water that is being lost by evaporation. In Denver there are 69 inches of evaporation and 49 inches of deficiency. That is about the way it is throughout the whole arid region. The question then is, when you have the stable and the horse, where will the feed come from. Anything that will decrease evaporation is of importance And it is important that it should be attended to now, while it is possible to preserve that which will decrease evaporation—namely, our forests.

In order to aid in looking after those in the broader areas you should have timber belts all through your arid region to help irrigation.

The CHAIRMAN. The great problem now is to reserve the timber belts that we have and to preserve them from the dreadful destruction by fires to which they are subject each year. The fires in summer make alarming havoc in the forests. This committee rode from the Yellowstone, where we struck the mountains, in Montana, to Tacoma, through so thick a smoke, for 1,000 miles, that we could not see a mountain on either side. Have you anything practical to suggest as to how, before the country gets settled up, and gets it under control, as they do in older countries, to check those forest fires? Have you studied that question?

Mr. FERNOW. Yes.

The CHAIRMAN. Have you mentioned it in your report?

Mr. FERNOW. I have done so in various reports, though I do not think I have done it in this report. It can be done, however. It is only a matter of good-will. It has been said that it could not be done on account of the expense. We have the money and we have the peo-

ple. It is a very easy thing in mountain regions to control a large area with a small force, even against fires. It would be easy to use fire for the purpose of checking fire. By burning over some parts at the proper time, taking proper pains to have guards established in certain belts, whenever a fire should break out—and it will be impossible to prevent it—there should be a possibility of controlling it. At present it is a lack of possibility of controlling these fires that makes them so detrimental and makes them sweep over so large an area.

The forestry people have proposed for Canada a system of guards—a body of Government servants. The Government of Ontario has adopted the proposition—has appointed certain forest guards, whose duty it shall be to look through the country, each guard having his beat and putting out any fires that may be detected, the Government acting in co-operation with the lumbermen. One-half of the expense is borne by the lumbermen and the other half by the Government. The appointment of the men is made by the Government on the nomination of the lumbermen. The Government in Canada owns the forest area and only leases out the right to cut the timber.

Mr. Fernow submitted the following paper:

DEPARTMENT OF AGRICULTURE.
FORESTRY DIVISION.
Washington, D. C., June 30, 1889.

SIR: In obedience to your letter of April 21, referring to a request of the chairman of the Senate Committee on Irrigation, I have the honor of submitting the following report on those points of the inquiry which fall more more or less directly under the observation of this division, namely, in answer to the following proposed questions:

(5) The area of timber land within the dry section of the United States, west of the hundredth meridian.

(6) The extent and effects of tree planting.

(7) The influences of forests and forest culture on the conservation of water and their known or probable effects on the distribution of the water for irrigation purposes.

The time which could be devoted to the preparation of this report having been exceedingly brief, not much new material could be brought together, and the report is, therefore, mainly a condensed restatement of what has been discussed before in various reports from this division. In fact, the statistical material on hand for the answer of these questions is only meager and does not allow much direct and positive statements, which may cover the ground in all cases, nor could I attempt to use the material on hand exhaustively without unduly lengthening the report. Most of the report is therefore devoted to the general discussion of the relation of irrigation schemes to forcs conditions, and to a statement, as concise as possible, of what is known of the influence which the forest exerts upon water conditions.

In the form of appendices I have tried to furnish more special answer to the questions propounded and information which leads to their answer.

I append, also, as containing information directly bearing upon the subject of this report, Bulletin No. 2 from this division, which gives detailed information on the forest conditions of the Rocky Mountains, and a copy of my Annual Report for 1888, which discusses at length one of the claimed forest influences, namely rain-fall.

Through the courtesy of Mr. Abbot Kinney, late chairman of the California State Board of Forestry, I am enabled to append a clear and concise statement of the forest conditions and forest influences experienced in southern California. Thanks are also due for statements received from Col. E. T. Ensign, Forest Commissioner of Colorado; and G. C. Bracket, secretary of the State Horticultural Society, Kansas; and from Prof. Mark W. Harrington, of Ann Arbor, well known as authority in meteorological questions.

It is to be hoped that the subject of the relation of forests to water supply, as yet but little understood in our country, will receive the attention which its importance in connection with irrigation problems deserves, and that this division will be enabled to make a more careful survey of the forest conditions of the region and their relation to water supplies than has been possible with the limited means at its disposal.

Respectfully,

B. E. FERNOW,
Chief of Forestry Division.

Hon. EDWIN WILLETS,
Assistant Secretary.

THE RELATION OF IRRIGATION PROBLEMS TO FOREST CONDITIONS.

By B. E. FERNOW.

The following report has been written under a full realization of the importance which the discussion on the relation of forest-cover to water conditions must assume at the present juncture.

The importance and magnitude of the investigations into the problem of irrigation for the Western arid regions can not be overrated; it may be likened to the discovery of a new continent, not by a lucky adventure, but by knowledge, skill, science, and art.

In such an enterprise every factor bearing upon the problem must be carefully considered, every means which may help to increase and properly utilize the scanty supply of moisture must be employed, if we expect to produce the highest attainable result, if we intend to bring the largest possible area into fruitful condition.

The main question of the problem is, by what means can the precipitation falling over the area comprised in the arid region be made to do the most duty? And the special proposition to be discussed in the following report is whether, in what manner, and to what extent a forest cover may be expected to assist in the thorough utilization of the precipitation and atmospheric humidity for agricultural purposes; although, in the consideration of a great national enterprise which like the one proposed is to promote the development of a poorly timbered or treeless country, the significance of the forest in all directions, as a source of raw material, of health, of comfort, etc., should also find proper recognition.

The relations of water conditions of the earth and vegetation in general is graphically expressed in the words of a poet who speaks of "Afric's arid sand where nothing grows, because it does not rain; and where no rain does fall, because there nothing grows."

This interdependence of vegetation and moisture conditions has been experimentally proved; it is only an apparent paradox when we say that the presence of vegetation is at the same time a necessary condition of its existence.

This is especially true of the forests. The forest, by its growth, creates its own favorable conditions of growth. The treelessness of the plains and of much of the arid region may possibly explain itself in this way. By the destruction of the forest which originally covered this region, the very condition of its existence and of its natural recuperation was destroyed; and thus in a reverse manner, reforestation of parts by artificial means may make natural reforestation over the whole area possible by and by.

"A tree by itself is doomed where a forest once established is comparatively secure."

The failures in forest culture on the Western plains may be considered mainly due to the fact that tree-planting and not forest planting has been attempted.

The discussion of forest influences has, unfortunately, become a popular one, before a proper and positive basis has been established for it by scientific investigation and observation. This is unfortunate, because the consequence has been that extravagant claims have been made by popular writers without proper basis, and, on the other hand, the overstatements have created a distrust in the offices claimed for the forest, even in the minds of some scientific men. The very popularity of the theory of forest influences seems to be sufficient reason for these to deny and scorn their existence. A competent writer, presenting a popular treatise on this subject, says, with proper emphasis, "Nobody is entitled, at the present stage of our knowledge, to declare the question of forest and water settled one way or the other. Nobody who has not the fundamental knowledge of meteorological science and scientific observation is entitled to participate in the discussion, and the public at large, especially, can only be called upon to study and reflect, but not to take sides in blind partisanship."

Unfortunately, again we are called upon to act upon the strength of our convictions in this question; we are called upon to conserve, perpetuate, and husband carefully our remaining woodlands, on account of their influence upon climate, soil, and water conditions; or else to disregard this claimed influence.

Those who doubt the existence of such influences—some of which are proved beyond doubt—should not forget that the first conception and rational explanation of the existence of forest influences originated with the profoundest student of nature that this century has produced—Alexander von Humboldt—and such able observers as Buffon, Boussingault, and Becquerel sided with him; and in our own country the ablest writer on the subject, George P. Marsh. Let them also consider that forest destruction is the easily and readily accomplished task and is the tendency of mankind, while forest conservation is possible only to the rationally-thinking, the civilized, progressive man.

It is, therefore, at present, still the duty of a government to give preponderance to the weight of opinion on the positive side, which seems well supported by experience as well as argument, and to shape its policy accordingly.

Considering the relation of forest conditions and irrigation problems with reference to the special case of the arid regions of the West, the writer, after much study and a hurried and partial inspection of the ground, feels justified in stating briefly and boldly, without being able to argue them at length, the following conclusions:

(1) Reforestation on the plains and forest preservation on the mountains is of greater national concern than the location of irrigation reservoirs.

(2) While the location, construction, and systematic regulation of such reservoirs, under Government control is, under given conditions, feasible and desirable, their purpose will be better subserved, if, at the same time, attention be given to forestry in connection with the irrigation systems.

(3) While forest preservation and extensive reforestation not only are coadjutators of irrigation system, but supply in part the conditions which irrigation and reservoirs are designed to accomplish, neither the one nor the other will invite private enterprise, at least for a long time to come; on the other hand, the location of irrigation reservoirs and ditches has been and will be, as need arises, accomplished by private enterprise. This statement is made without disparaging any attempts on the part of the Government to assist such private enterprise and to give it systematic direction.

(4) Certain difficulties and dangers which attend the construction of reservoirs will be increased by continued forest destruction in the mountains, induced by the neglect on the part of the Government to rationally administer this valuable property of the nation; and these dangers and difficulties will be avoided or reduced by a national forest administration and reforestation.

Such conclusions are based mainly on the assumption that a forest cover exerts certain influences which affect conditions of water supply and other climatic conditions.

When considering these influences, especially with reference to agricultural pursuits, it is a mistake to discuss them separately, since vegetation does not depend on any one factor of climate, but is rather the balancing of several factors which produces favorable conditions of growth. Vegetation does not, as is so often stated, depend on rain-fall—certainly not on the mean annual rain-fall—but on conditions of atmospheric as well as soil humidity and conditions of transpiration and evaporation respectively.

The simple mechanical impediment, then—a timber-belt or even a single row of trees opposed to the progress of a drying wind—is sufficient to affect the crop under the shelter of a windbreak, lowering the rate of evaporation and transpiration.

Therefore agriculturists in regions with plenty of rain-fall yet find it advantageous to have recourse to irrigation in order to supply the exhaustion by rapid evaporation and transpiration. The wonderful growth of the Sequoias on the Pacific coast and Sierra Nevada finds certainly not its explanation in the amount of rain-fall, which in the former locality is less than on the Atlantic side, and occurs nearly all in winter with hardly any in summer. But the mists and fogs coming from the ocean reduce the rate of evaporation and help to economize the moisture of the soil during the long period of vegetation. One of the most important studies in connection with irrigation problems will be that of the rate of evaporation and of the influences promoting or retarding it.

In this direction hardly any data are as yet collected, and we can hardly anticipate how much a single "chinook" of twenty-four hours' duration may waste the water of a reservoir or dissipate the snow which lacks the protective forest cover.

If, as is claimed, there has been observed in the plains region any effect of tree-planting on water-supply, it is most likely this mechanical effect which the timber-belt or wind-break exerts, allowing a better utilization of the moisture by the crops. At first sight this mechanical shelter may appear of too restricted a character to deserve notice, yet many facts concur in showing that it is a most important element in local climate. According to Becquerel, a simple hedge 6 feet in height will give protection for a distance of 70 feet; and, according to Hardy, a belt of trees every 300 feet will defend vegetation against the action of the wind. Every traveler in the prairie will have experienced the calm which a small growth of shrubs not higher than 6 feet creates, while the wind is blowing many miles an hour outside of this shelter. Quite a number of instances can be cited where the crop thus protected had outlived the parching blast from the South, while the neighboring field was destroyed by the rapid evaporation. In fact, this influence of a wind-break as a mechanical barrier to the progress of winds is so well understood that it requires no discussion, no argument.

That a timber-belt, and more so a succession of timber-belts, will afford so much better protection is evident.

Thus, if no other influence were conceded to the forest in the plains, this one,

which tends to conserve the moisture within the range of its protection, would make systematic forest plantations a most desirable adjunct to irrigation systems.

Summer and winter drought, *i. e.*, rapid evaporation, is the bane of the farmer in the plains; and this is due to the continuous dry winds, which can be checked by rationally disposed timber-belts.

Another merely mechanical influence which needs no argument or discussion with the observer of natural phenomena, is that which the forest cover on the mountain-sides exerts in retarding the melting of the snow and the drainage of the water, thus prolonging the period during which the same may be made available. Complaints that the snows do not lie as long into the summer as they used to, before the forest-cover was removed, may be heard all along the eastern Colorado Slope, where irrigation has been practised in the most rational manner and the waterflow the best observed. By the rapidity with which the water now flows off the bared mountains the effectiveness of the ditches is reduced by four to six weeks, there being an accumulation of flow at a time when it can not all be utilized and a dearth later on when it could well be used.

Some one, evidently but little conversant with the economies of nature, has suggested that in connection with the reservoir system it would be desirable to remove the forest cover, so that the snows may drift into the cañons, there to slowly give up their waters to reservoirs and ditches. Even if the favorable results thus anticipated could be reasonably expected to follow, the dangers invited by this method of storage are simply incalculable. These have been over and over again, and *ad nauseam* pointed out in various reports, and the consequences of deforestation have so palpably been experienced by European countries not only, but even in our own, that it seems a waste of energy to rehearse them again. They are briefly the following: First, more rapid melting of the snows, especially under the marvelously exhausting influence of a "chinook;" secondly, the more rapid flow of surface waters, which carries with them the thin mold and earth, gradually baring the rock and ending up in the creation of destructive torrents, which in France have carried débris over fertile lands 150 to 200 miles into the plain, to correct which an expenditure of more than $50,000,000 has been necessary. By the destruction of the natural storage which the forest offers for snows and rains, giving up their waters gradually and for a longer period, we invite floods and droughts alternately.

The conditions, in the Rocky Mountains at least, are quite similar to those of the French Alps, and, in fact, the experiences, although only limited on account of the undeveloped state of their territory, have been quite similar, especially around Greeley and Colorado Springs. Among the dangers and difficulties which attend the construction and maintenance of reservoirs are, in the first place, their incapacity of taking care of flood waters and their liability to unforeseen bursting. In regard to both these points I call attention to the experiences of French engineers, related in the "Annales des Ponts et Chaussées," some of which are also given in George P. Marsh's classical volume, "The Earth as modified by Man." These dangers are particularly increased by the conditions of rain-fall in the region under discussion, the rains being occasionally very heavy and in the nature of cloud-bursts. Professor Harrington reports one such cloud-burst which resulted in a flood, carrying away miles of railroad track on the level at the base with such violence that the rails were bent. The recent experiences in Pennsylvania, Virginia, and other parts of the country will serve as testimony of the force of such water accumulation.

The reservoirs must be built on such contingencies, and a study of the cloud-bursts in the irrigation area is therefore highly desirable, especially as they are not as yet matters of regular record. That cloud-bursts, like all violent exhibitions of meteorological phenomena, seem to occur more often in large unwooded areas, may also point again to the employment of reforestation, as a preliminary or concomitant of the construction of irrigation reservoirs in the prairies and plains, as a measure of protection.

The following passages from good authorities exhibit pretty well the relation of forest cover to irrigation problems.

Mr. Hubert Vischer, engineer to the State Forestry Board of California, uses the following language in his report to the board:

"The agricultural development of the uplands of the coast range—and there is little else but uplands—will be as dependent upon irrigation in time as are the lands of the southern portion of the State now.

"Referring to our notes upon the general hydrographic conditions of the range, it may be inquired how water can be procured? The location of the main streams being depressed and their grade slight, to bring water upon uplands would imply outlays which the value of the lands will never warrant. Storage of water in the tributary streams and gulches can not succeed, owing to the precipitous slope of their channels and the consequent lack of storage depth. Storage of water upon higher-lying lands may, in special cases, succeed, but generally will be unfeasible, as the arable lands which it is sought to water are themselves in most cases situated at

considerable elevations. Wells and the development of springs will be found, like the last expedient, only applicable in exceptional cases.

"Of all the means of storing water only one remains—nature's own means. It is only necessary to prolong the flow of natural channels for a short period—a month or a fortnight would often suffice—and to accomplish this is within the power of being effected by stimulating tree growth upon very limited area of ground, especially if due regard be had for impounding snow where practicable;" and Mr. E. S. Nettleton, former State engineer of Colorado, says in regard to forest conditions and water supply: "The fact that our system of farming has changed within the past few years by substituting for the summer crops those which require water earlier in the spring and later in the fall, makes it more important than ever to secure as uniform a flow of water in our irrigation streams as is possible to do throughout the whole irrigating season.

"To accomplish this end, I call your attention, first, to the importance of the preservation of our mountain forests, and the recovering of the mountain districts with a new growth of timber. The details of how this work is to be accomplished, and the arguments proving the benefits to be derived therefrom, I will leave for abler ones to discuss. I take it for granted that some will say, 'This forestry subject is one of the future; we want something of immediate benefit and relief.' While this may be true in part, yet the protection and preservation of the mountain forest of the present day is an immediate necessity, if we desire to protect our streams from an intermittent and diminished flow.

"Neglecting to take steps toward preserving the forests and encouraging the recovering of the mountain sides with timber, because we can not see immediate and profitable returns, is no good excuse.

"We should do this much for the benefit of those who are to follow us, and who will make this country equal at least to any of the irrigated countries in olden times, which history tells us have supported a much denser population than is possible to support in a country where the people have to depend on rain-fall for a more or less successful agricultural industry."

Another important influence of the forest, in connection with irrigation problems, is its tendency to raise the water-level in its immediate neighborhood; a well established fact.

The forest influences, which may reasonably be claimed to exist, have been discussed in my report for 1886, which is herewith appended. Such forest influences are claimed to exist in the following directions:

(1) On sanitary conditions.
(2) On local climate.
  (*a*) On temperature conditions.
  (*b*) On humidity of atmosphere.*
  (*c*) On distribution of rain-fall in time, and, locally perhaps, on quantity.
(3) On soil conditions, on water-level, and on water-flow.

The question of forest influence on the amount of rain-fall has been discussed at length in my report for 1887 also appended; from which it will appear that there are no data as yet on hand upon which the questions may be even qualitatively settled.

There is one point to which the writer would call special attention and which has too often been lost sight of when discussing the influence of the forest on climatic conditions, namely, that the condition of the forest itself plays a very important part in determining its influence. Such conditions are given in the extent, the density, the position, the composition of the forest and the age or height of the tree.

It has been very generally overlooked that these conditions of the forest are of greatest moment and may alter absolutely the nature of the influence, so that the exact opposite of the expected influence may become apparent; when, for instance, a forest on the leeward of a water surface deprives the open land beyond of the benefit of this water surface.

The influences exerted by the forest can, almost all, be referred to the mechanical barrier which it interposes either horizontally or vertically to the action of the sun or the winds, or to the percolation of water; hence the nature of this barrier, its extent, density, and continuity must needs determine the nature of its influence.

In conclusion, the writer deems it proper in this place to call attention to the culpable ignorance of the bearing which the forests of the Rocky Mountains and California have upon the water supplies and irrigation problems, as exhibited in the management or rather absence of management of the same on the part of the Govern-

*Definite statements of the observed influence of deforestation on the conditions of atmospheric humidity will be found in the report of Hubert Vischer to the California State Board of Forestry, where the effect of the removal of the redwood forests around Humboldt Bay is noted. This report deserves special attention for the clear and business-like manner in which it treats of the present conditions and future of the north California forests and their relation to the development of the country.

ment. This matter has formed the basis of the appended report on the forest conditions of the Rocky Mountains, where the deplorable state of affairs has been set forth in unequivocal language.

It would be indeed a most irrational proceeding to promote the establishment of irrigation reservoirs, without at the same time arresting the irrational forest destruction which is invited by the neglect of Government to administer its property rationally.

APPENDIX A.

AREA OF TIMBER LAND WITHIN THE DRY SECTION OF THE UNITED STATES WEST OF THE HUNDREDTH MERIDIAN.

This section comprises regions of widely different character topographically and climatically, and the distribution of forest areas is accordingly a different one in the various regions.

PLAINS REGION.

The plains region, which may be said in general, to comprise the area east of the 7,000-foot level, is practically without timber lands; the only trees are found lining the banks of the larger streams, sometimes in clumps or even groves of from 100 feet to one-half a mile in width, the species found belonging to the Atlantic forest and consisting mainly of cotton-wood, elm, green ash, box-elder, hackberry. Going westward even these fringes of trees cease and the only occasional trees seen are cotton-woods.

This timberless region may be estimated at, roughly, 400,000 square miles.

The only mountain islands within this region, which are forested, are the Black Hills in Dakota and Wyoming, with about 2,400 square miles more or less wooded, and some of the mountain ranges in southeastern New Mexico of similar extent.

Altogether it would be difficult to find as much as 2 per cent. within this vast area that shows what may be fairly called a timber growth.

ROCKY MOUNTAIN REGION.

The area of the Rocky Mountain region proper has been carefully canvassed and set forth in the accompanying report on the forest conditions of the Rocky Mountains.

From the data given in the report, the following table is constructed, which approximates the ratio of mountain land and plains and gives the forest area which is found in the region by counties. From this we find, that of the 269,881 square miles which fall within the mountain region proper, 22.23 per cent. is reported as timbered, representing 60,075 square miles (38,400,000 acres).

MONTANA.

Counties.	Area.	Mountain.	Plains.	Total forest.	Mountain forest.
	Sq. miles.				
Beaver Head	2,800	2,800	.....	1,100	1,100
Choteau	26,000	.....	26,000	350	.....
Custer	20,000	.....	20,000	200	.....
Dawson	2,700	.....	2,700	200	.....
Deer Lodge	5,000	5,000	.....	2,400	2,400
Fergus	7,500	.....	7,500	700	.....
Gallatin	7,100	7,100	.....	1,600	1,600
Jefferson	2,200	2,200	.....	350	350
Lewis and Clarke	2,100	1,100	1,000	400	400
Madison	4,500	4,500	.....	900	900
Meagher	5,700	3,000	2,700	1,100	1,100
Missoula	24,500	24,500	.....	16,200	16,200
Silver Bow	576	576	.....	60	60
Yellowstone	3,600	.....	3,600	25	.....
Crow Indian	7,200	4,000	3,200	700	700
Indian reservations	24,300	.....	24,300	.....	.....
Total	145,776	54,776	91,000	26,285	24,810

Mountain forest, 24,810=45.4 per cent.

COLORADO.

Counties.	Area.	Mountain.	Plains.	Total forest.	Mountain forest.
	Sq. miles.				
Arapahoe	4,700	.....	4,700	.....	.....
Archuleta	1,026	1,026	.....	450	450
Bent	9,070	.....	9,070	.....	.....
Boulder	768	768	.....	275	275
Chaffee	900	900	.....	500	500
Clear Creek	450	450	.....	200	200
Conejos	1,320	1,320	.....	300	300
Costilla	1,450	1,450	.....	450	450
Custer	750	750	.....	200	200
Delta	1,150	750	.....	500	500
Dolores	800	800	.....	150	150
Douglas	850	850	.....	300	300
Eagle	1,750	1,750	.....	300	300
Elbert	5,800	.....	5,800	100	.....
El Paso	2,650	1,300	1,350	500	.....
Fremont	1,450	1,450	.....	450	450
Garfield	7,250	7,250	.....	800	800
Gilpin	140	140	.....	50	50
Grand	1,800	1,800	.....	700	700
Gunnison	4,000	4,000	.....	1,200	1,200
Hinsdale	1,440	1,440	.....	450	450
Huerfano	1,160	1,160	.....	250	250
Jefferson	760	760	.....	175	175
Lake	420	420	.....	200	200
La Plata	4,000	4,000	.....	1,500	1,500
Larimer	4,000	4,000	.....	700	700
Las Animas	6,500	.....	6,500	500	.....
Logan	3,000	.....	3,000	.....	.....
Mesa	3,850	3,850	.....	275	275
Montrose	2,040	2,040	.....	640	640
Ouray	190	190	.....	110	110
Park	2,000	21,000	.....	600	600
Pitkin	1,090	1,090	.....	540	540
Pueblo	2,350	1,200	1,150	125	.....
Rio Grande	1,300	1,300	.....	275	275
Routt	6,200	6,200	.....	1,050	1,050
Saguache	3,150	3,150	.....	1,175	1,175
San Juan	450	450	.....	100	100
San Miguel	1,375	1,375	.....	260	260
Summit	750	750	.....	275	275
Washington	2,220	.....	2,220	.....	.....
Weld	5,300	.....	5,300	.....	.....
Total	100,200	61,129	39,070	16,625	15,400

Mountain forest, 15,400=25 per cent.

WYOMING.

Albany	6,922	6,922	.....	840	840
Carbon	13,526	13,526	.....	1,360	1,360
Crook	10,709	.....	10,709	400	.....
Fremont	20,957	20,957	.....	3,300	3,300
Johnson	11,121	11,121	.....	1,800	1,800
Laramie	11,200	.....	11,200	80	.....
Sweetwater	10,550	10,550	.....	40	40
Uinta	12,140	12,140	.....	2,400	2,400
Yellowstone Park	3,259	3,250	.....	1,840	1,840
Total	100,366	78,466	21,900	12,060	11,580

Mountain forest, 11,580=14.8 per cent.

NEW MEXICO.

Bernalillo	8,350	8,350	.....	1,450	1,450
Colfax	7,000	.....	7,000	1,275	.....
Dona Ana	10,260	10,260	.....	75	75
Grant	10,090	10,090	.....	800	800
Lincoln	24,450	.....	24,450	920	.....
Mora	3,830	.....	3,830	720	.....
Rio Arriba	7,500	7,500	.....	175	175
San Juan	7,200	7,200	.....	250	250
San Miguel	11,630	.....	11,630	1,300	.....
Santa Fé	2,490	2,490	.....	1,375	1,375
Sierra	3,200	3,200	.....	250	250
Socorro	16,500	16,500	.....	2,050	2,050
Taos	2,300	2,300	.....	900	900
Valencia	7,700	7,700	.....	960	960
Total	122,500	75,510	46,990	12,500	8,285

Mountain forest, 8,285=11 per cent.

SUMMARY.

	Square miles.	Acres.
Total area	468,851	300,064,640
Total mountain area	269,881	172,723,840
Total plains area	198,970	127,340,800
Total forest	65,470	41,900,800
Total mountain forest	60,075	38,448,000

Mountain forest equals 22.23 per cent. of total mountain area.
Mountain forest equals 92 per cent. of total forest.

INTERIOR BASIN.

The area of timber land in the States which partly make up the Interior Basin is approximately as follows:

Washington.—Total forest area estimated at 30,000 square miles. The bulk of this lies in the eastern part of the State west of the Cascade Range. The counties which may be referred to as parts of the arid region, the timber land in which is confined to the spurs and ridges and to the east slope of the Cascade Range and to the Blue Mountains, namely, Spokane, Whitman, Walla Walla, Columbia, Yakima, Klickitat, contain approximately 6,500 square miles or 23 per cent. of their area more or less forested. The interior, however, is entirely destitute of tree growth, the few trees along the rivers having mostly been cut. The yellow or bull pine is the main timber, with red fir, hemlock, spruces, and other conifers added on the better sites.

Oregon.—The total timbered area of the State is estimated at 30,000 square miles, confined mainly to the Western mountain ranges and the Blue Mountains in the northeastern part of the State.

The counties which fall within the dry section, namely, Umatilla, Union, Grant, Wasco, Lake, and Baker, a total area of round 63,000 square miles, have about 12,000 square miles timbered, or less than 20 per cent. Yet, with the exception of the forests of Wasco and Lake Counties on the eastern slopes of the Cascades, the timber growth is mostly open and scattered, even on the Blue Mountains, and the trees of stunted growth. Yellow pine, red fir, and larch are the principal trees, with lodgepole pine on summits.

Idaho.—With the exception of four counties—Kootenai, Lemhi, Nez Pérces, and Shoshone—which belong to the Rocky Mountain region proper, or are otherwise climatically outside of the dry region, the rest of the State, with over 69,000 square miles, may be considered part of the Interior Basin. This part contains of timbered land an estimated area of 9,140 square miles, or about 13 per cent. The bulk of this lies north of the Snake River; the counties south of this river may be said to be almost timberless, containing less than 1 per cent. of forest area in confined localities and of scattered growth.

Utah.—The area west of the Wahsatch Range with round 30,000,000 square miles may properly be considered as part of the Interior Basin and counted practically timberless, excepting a few mountain ridges which bear a stunted growth of juniper and piñon in their recesses. The forest area of the State which is found in the mountain ranges and on the high plateaus extending in a southwesterly direction, is estimated at 6,000 square miles, or less than 12 per cent. of the area within which it is found, the timber being found of inferior size and quantity and mostly confined to the cañons. The Colorado River plateau is for the most part untimbered.

Arizona.—The total forest area is estimated at round 15,000 square miles, or less than 14 per cent., and is confined to the high Colorado plateau above the 7,000-foot level, where a considerable body of continuous though open timber growth is found, and to the mountain ranges in the southeast. Along the streams and cañons are also found scattered deciduous trees. The yellow pine is the most valuable timber tree. The southern part shows in its tree growth Mexican types like the acacias, mesquites, and others. A scrubby growth of oaks and junipers furnishes needful fuel for domestic use and in mining operations.

Nevada.—This State, as a whole, is treeless, the most barren and naked in the whole region, with less than 3 per cent. or only 3,000 square miles bearing a timber growth, and that of little account, except around Lake Tahoe, where it has been, however, largely cut. In other parts the tree growth is confined to the recesses of the mountain ridges in the central and southern portions of the State, consisting of a stunted growth of *Pinus flexilis* (white pine), scrubby piñon on the lower slopes, mountain mahogany, and occasional junipers.

California occupies part of the Interior Basin, with portions of all the counties which cross the Sierra Nevada and which mostly also form part of the Sacramento

and San Joaquin Valleys. A separation of the area of timber land which occupies the region under discussion from that on the Coast Ranges and Sierras, is well-nigh impossible.

The southern counties of California south of the interior valleys, with about 50,000 square miles, are estimated to have 1,000 square miles timbered, occupying the cañons and the tops of mountain ranges above 3,000 feet. The area absolutely or nearly timberless east of the Sierra may be calculated at about 23,000 square miles, of which perhaps 2 per cent. has a timber growth on the mountain ridges and slopes. The interior valleys, comprising a total area of about 34,000 square miles are more or less timbered; 4,000 to 5,000 miles may be estimated as entirely destitute of timber, and 15 per cent. of the balance—or 4,500 square miles—may be considered well timbered, while an open growth of oak of little value is found to cover, more or less, all the land that is not cleared.

There are, however, no data on hand which allow even a reliable estimate of these conditions. The map of the State Forestry Board of California, which promises to analyze the forest areas, is not yet available for this report.

APPENDIX B.

THE EXTENT AND EFFECTS OF TREE PLANTING IN THE DRY REGION.

Forest planting, or rather tree planting—for the planting is as yet hardly anywhere done in such a manner as to deserve the name of forest planting—has been practiced to a limited extent; enough, however, to show that it can be done, with or without irrigation, if properly attended to. The twenty-five counties of Kansas which are entirely and seven more which are partly within this region, report 39,810 acres of timber trees, seedlings, and older plants, growing in 1888. Most of this is cottonwood, walnut, honey locust, green ash, box-elder, elm, hackberry, catalpa, mulberry, Osage orange, and some few other varieties; all of the Atlantic forest trees have been grown successfully. Some successful tree planting has also been done without irrigation in Colorado and Nebraska west of the one hundredth meridian, but its extent is not known. A small amount of timber planting has also been done in the region of the Interior Basin, and a larger amount in California, where groves of considerable extent are in existence.

Statistics, from which to estimate the area of artificial timber, are not on hand outside of those given for Kansas. A canvass, to ascertain how many plantations over 5 acres in extent there were in existence, was attempted two years ago, but the returns give, evidently, no reliable result, and are therefore here omitted.

It would seem that the entries under the timber-culture act should furnish, at least approximately, an idea of the area planted to timber, but since it may be said that the majority of these entries have not only changed hands and thus appear in the annual statement repeatedly, but have also been changed to entries of other kind, no result can be obtained from the study of these figures.

The status of timber-claim planting is exhibited in the appended table. From this it will appear that 38,985,910 acres were entered under the timber-culture act up to June 30, 1888. This should represent a planted area of 2,436,620 acres, if the law were complied with and the entries not changed. Allowing ten years for timber-claim planters to prove up their entries (the law places it at eight years, allowing extensions on account of failures), the entries of the first six years—from 1873 to 1878—alone give us some point of comparison for the estimation of result. During that time 4,394,256 acres were entered, while only 783,838 acres or 17.8 per cent. of these entries were proved up, representing an area assuredly planted of less than 50,000 acres.

It is asserted that a better percentage will be obtained from the entries of later years. Altogether, however, the consensus of unbiased testimony goes to show that timber-claim planting, as a rule, does not produce the results sought after and has mostly been used as a means for speculation in Government lands.

There is also considerable planting of wind-breaks and groves done on homesteads, which is said to be attended with better results.

Altogether, however, the amount of tree planting is infinitesimal if compared with what is necessary for climatic amelioration, and it may now be recognized as well as later, that the reforestation of the plains must be a matter of national enterprise, which can not be expected from the individual citizen.

The reforestation of the plains as well as the preservation of the forests on the Western mountains, is, in fact, of greater national concern, and requires in greater degree national action than the proposed irrigation surveys.

As to the effects of the tree-planting on climatic conditions but little can be said, and the statements of opinion which refer any climatic changes to this factor must be taken with caution. There is, however, one influence which can be claimed without dispute, that of breaking the force of winds locally and protecting houses and single fields that lie within the cover of a windbreak or grove against the deleterious influence. I call especial attention to the observations on this point in the appended letter of Mr. Kinney. The experience there recorded is that had in all parts of the region, and records are on hand showing the distance to which a windbreak would protect a field against a burning southwester, while the neighboring unprotected field would succumb to the blast. The consequence of this mechanical action of the trees would also tend to diminish the rate of evaporation. This is probably all the effect —and one not to be underrated—which is due to the tree-planting in extensive shelterbelts and occasional small groves. To produce considerable changes in temperature or increased precipitation, the planting is done in too small parcels and the growth not old enough, and is also mostly too open to effect that marked difference of insolation over the forest and the field which makes the former a factor in climatic influences.

To produce great climatic changes the operations must be on a larger scale, more contiguous, and with more intent to shade the soil than has been hitherto the practice.

In this region are situated several military reservations, which could be devoted to no better purpose than planting them to forest many sections at a time. Such planting would not only furnish an incentive for imitation by settlers and supply them with plant material, it would improve conditions in the immediate neighborhood and form a nucleus for the national forest administration, which is now a necessity and whose inauguration can only be a question of time.

Entries under timber-culture act.

Years.	Initial entries.	Final entries.
	Acres.	
1873	50,246	
1874	851,225	
1875	493,694	
1876	607,984	
1877	520,673	
1878	1,870,434	
1879	2,766,573	
1880	2,193,184	
1881	1,763,799	
1882	2,566,686	23,371 acres, or 46.5 per cent. of entries of 1873.
1883	3,110,930	97,836 acres, or 11.5 per cent. of entries of 1874.
1884	4,084,464	91,600 acres, or 18.5 per cent. of entries of 1875.
1885	4,755,006	90,301 acres, or 14.8 per cent. of entries of 1876.
1886	5,391,309	141,694 acres, or 27.2 per cent. of entries of 1877.
1887	4,224,398	204,620 acres, or 10.9 per cent. of entries of 1878.
1888	3,735,305	134,416 acres, or 4.9 per cent. of entries of 1879.
	38,985,910	783,838 acres, or 17.8 per cent. of entries first six years.

	Acres.
Entries first six years	4,394,256
Entries last ten years	34,591,654

The year 1882 was the first in which, under the terms of the act, final entry could be made. The original act of 1873 required 40 acres of every 160 to be planted with trees, "not more than 12 feet apart each way." By an amendment of 1878, only 10 acres of every 160, and the same proportion for smaller sections were required to be planted, but 2,700 trees were required to be planted on each acre instead of the 302 under the original act; and on final entry at least 675 thrifty trees were to be growing on each acre. The amendment was made applicable to all final entries, obliging those who had made entries under the act of 1873 to have trees enough growing at the time of final entry to make the number of acres required by the act of 1878.

Original and final entries under the timber-culture laws from 1873 *to* 1888.

States.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.
	Initial.	Initial.	Initial.	Initial.	Initial.	Initial.	Initial.	Initial.
Arizona	.....	196.51	320.10	1,197.15	2,440.00	1,600.00	3,280.00	719.65
California	329.75	8,878.06	29,065.53	20,524.23	10,586.05	8,029.42	14,458.81	12,120.31
Colorado	.....	2,272.24	3,453.82	6,514.22	3,343.33	17,436.73	16,142.03	30,302.14
Dakota	3,560.00	124,997.29	61,969.75	119,835.23	68,266.92	579,804.04	728,687.83	868,748.39
Idaho	.....	180.83	2,583.25	1,973.89	7,035.91	22,169.53	22,013.93	23,300.04
Iowa	145.96	3,816.05	9,127.52	8,563.42	4,791.56	7,535.47	6,577.67	4,714.05
Kansas	9,642.17	282,479.07	168,269.06	185,596.43	238,020.44	593,295.17	1,167,582.77	408,261.74
Louisiana	.....	.....	.....	.....	.....	.....	80.43	40.00
Minnesota	14,710.15	113,131.63	63,673.73	140,126.30	76,021.53	377,017.78	257,642.50	123,735.36
Montana	.....	.....	.....	.....	398.59	960.00	3,134.20	6,835.32
Nebraska	21,858.07	312,712.09	130,894.26	106,499.74	90,812.90	195,306.68	465,968.94	475,275.87
Nevada	.....	.....	.....	.....	240.00	600.00	160.00	560.00
New Mexico	.....	.....	.....	1,128.00	.....	320.00	1,891.93	2,887.95
Oregon	.....	.....	882.68	1,793.18	2,509.37	18,446.21	17,046.59	73,061.66
Utah	.....	.....	.....	399.88	338.50	1,280.00	2,328.93	4,044.05
Washington	.....	2,482.22	3,324.14	5,374.28	19,746.75	78,237.00	68,506.10	134,637.65
Wyoming	.....	80.00	130.47	160.00	.....	.....	.....	240.00
Total	50,246.04	851,225.99	473,694.53	599,917.97	524,551.85	1,902,038.03	2,775,502.66	2,169,484.18

States.	1881.	1882.		1883.		1884.	
	Initial.	Initial.	Final.	Initial.	Final.	Initial.	Final.
Arizona	760.00	1,352.77	.....	4,336.85	.....	5,483.10	.....
Arkansas	.....	.....	.....	160.00	.....	80.00	.....
California	24,538.28	39,882.99	.....	44,190.05	160.00	72,340.65	160.00
Colorado	26,473.31	47,436.05	160.00	58,685.02	.....	137,933.07	160.00
Dakota	868,400.36	1,446,532.34	521.68	1,745,419.58	14,968.12	1,748,640.22	21,870.93
Florida	.....	.....	.....	.....	.....	320.00	.....
Idaho	28,680.26	33,965.61	.....	40,105.17	.....	56,171.52	80.00
Iowa	3,644.25	6,235.62	.....	3,373.40	2,165.33	3,346.17	2,794.93
Kansas	268,575.09	273,053.55	9,915.52	237,860.95	24,965.06	397,525.25	23,093.70
Louisiana	2,293.40	1,004.02	.....	7,754.26	.....	38,788.88	.....
Minnesota	167,582.16	176,741.42	2,998.50	122,750.39	11,495.25	95,538.50	12,324.75
Montana	16,535.20	35,409.94	.....	53,952.71	.....	63,283.25	.....
Nebraska	240,306.94	298,520.11	9,975.42	481,704.70	43,522.32	1,068,806.66	30,040.91
Nevada	1,040.00	1,520.00	.....	280.00	.....	159.79	.....
New Mexico	2,039.26	3,351.99	.....	22,091.82	.....	17,945.83	.....
Oregon	31,176.40	88,038.77	.....	116,334.14	240.00	148,356.16	160.00
Utah	3,921.52	3,831.71	.....	7,509.99	.....	11,192.09	.....
Washington	77,008.62	87,524.76	.....	139,737.05	320.00	173,142.27	914.44
Wyoming	784.30	2,284.44	.....	14,204.15	.....	46,027.62	.....
Wisconsin	40.00	.....	.....	.....	.....	.....	.....
Total	1,763,799.35	2,546,686.09	23,571.12	3,110,930.23	97,836.08	4,084,463.87	91,599.66

States.	1885.		1886.		1887.		1888.	
	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.
Arizona	19,542.87	160.00	15,772.93	160.00	20,199.99	320.00	45,374.52	.....
Arkansas	640.00	.....	2,025.22	.....	840.00	.....	660.00	.....
California	94,064.73	480.00	155,674.29	.....	165,382.29	40.00	240,216.76	49.82
Colorado	204,983.61	240.00	719,947.95	480.00	1,437,636.59	559.00	970,281.39	760.00
Dakota	1,328,966.24	21,207.06	1,116,250.72	39,591.67	650,420.88	57,311.41	626,629.79	29,996.36
Florida	.....	.....	.....	.....	.....	.....	160.00	.....
Idaho	48,255.01	.....	49,959.92	240.00	38,912.89	400.00	51,717.37	891.92
Iowa	3,647.43	1,437.63	2,869.03	1,014.00	2,187.30	2,888.56	4,945.80	1,207.26
Kansas	1,169,303.34	27,133.16	1,920,802.22	42,657.93	732,545.85	56,502.34	689,256.24	26,202.86
Louisiana	15,598.16	.....	9,914.50	.....	9,402.56	.....	11,469.63	.....
Minnesota	79,410.47	13,618.07	65,026.14	24,311.44	52,306.69	25,009.52	56,622.65	15,003.25
Montana	41,207.88	.....	43,031.12	160.00	38,847.15	280.00	36,407.58	39.68
Nebraska	1,468,114.28	24,767.28	969,706.78	28,278.93	794,047.24	52,541.82	660,915.58	48,264.82
Nevada	.....	.....	120.00	.....	640.00	.....	560.50	.....
New Mexico	16,288.10	.....	15,603.08	.....	23,695.75	.....	39,692.37	326.96
Oregon	97,331.30	160.00	93,160.05	880.00	93,137.44	920.00	126,979.96	4,406.68
Utah	15,842.86	80.00	25,632.56	.....	21,638.09	160.00	30,234.71	420.40
Washington	84,568.21	1,017.49	85,745.23	3,920.00	67,568.02	7,686.47	89,980.09	6,816.41
Wyoming	67,243.20	.....	100,107.64	.....	74,989.10	.....	53,260.16	.....
Total	4,755,005.57	90,300.66	5,391,309.38	141,693.97	4,224,397.83	204,619.62	3,735,305.10	134,416.12

Total number of acres entered from 1873 to 1888, inclusive, 38,958,558.45.

Total number of acres entered from 1873 to 1880, inclusive, 9,346,661.03; on which final proof and entry might have been made in 1888 or earlier.

Total number of acres on which final proof was made, 784,037,23, or 8.4 per cent. of possible number.

Total number of acres planted, 784.037 ÷ 16 = 49.002.

Total number of trees declared to have been planted and cultivated, 38,076,350, or less than one tree for each acre entered for timber culture.

APPENDIX C.

SOUTHERN CALIFORNIA.

"This portion of California is divided by parallel ranges of mountains, which here and there coalesce and become a confused mass of peaks. Between these ranges are valleys of various extent, but all of any agricultural value within 60 or 70 miles of the sea. To the east of the main Sierra Range lie the great deserts of Mojave and Colorado. These are broken by low barren hills devoid of any verdure whatever.

"The rain-fall varies between 25 inches at some points on the sea coast and mountain ranges, to 3 or 4 inches at points on the desert. The desert rain-fall usually occurs in summer. These conditions, as far as the United States are concerned, are peculiar to the Pacific slope. The result of this distribution of the rain-fall makes the use of water for irrigation essential for most crops not maturing in winter or the rainy season, and adds a great value to permanent water supplies for domestic as well as for agricultural puposes.

"The climate in this country is divided into a wet and a dry season. In the wet season it ought to rain but it often does not. In the dry season it ought not to rain but occasionally does.

"*Timber Area.*—Area of timber land in southern quarter of California—an area say, of 50,000 square miles—timber 1,000 square miles, or one-fiftieth of the whole. This timber is confined almost exclusively to the tops of the mountain ranges, and to an altitude varying between 3,000 and 8,000 feet. There is also a small amount of timber in the narrow cañons which carry the water from the mountains to the valley.

"While the forests of timber trees are thus shown to be very limited in extent, and far below the proportion which has been demonstrated in European countries to be needed for the best productive capacities of a country (about one-quarter), the brush, or chaparral, covers extensive areas in southern California. In Los Angeles County, which is the great agricultural producer of the south, timber trees cover one-twenty-fifth of its area, and are so inaccessibly situated in the mountains as to supply none of the immense demands for lumber of the community. One-third of the total area of the country is in chaparral. This brush-growth is from 2 to 12 feet in height. In some places it is so thick as to be almost impenetrable, while, as we pass to the back ranges and the desert, it becomes so thin and scattered as scarcely to be deemed of importance on the water-sheds.

"San Bernardino County has one-fiftieth of its area in timber, which is sufficiently accessible to be considerably used for local purposes; one-fifth of the area of this county is in brush.

"San Diégo County has about one-fortieth of its area in timber, which is used locally in a small way, and about one-fifth in brush

"The other counties composing the district have a somewhat smaller proportion of covering of forest and brush.

"The chaparral throughout the entire area is confined to the mountains and foot-hills.

"On the western and southern slopes of the first important ranges from the ocean it is densest. As we go back towards the desert the brush-covering decreases in density, until, on the desert itself, all the ranges are perfectly bare. The natural covering, as it now exists, is a reliable indication of the extent of the rain-fall, modified to some extent, perhaps, by the exposure of the mountain-growth. That on the northern, or shaded side, is proportionately greater than that on the southern.

"*Effects of deforestation.*—On the other hand, extensive areas of brush land have been denuded by fire, and some waste in this way has taken place among the timber trees. These have also been much thinned out in the localities named, from which lumber is being taken. The effects of this destruction of brush and timber have been plainly appreciable in every case.

"There have been two effects which have followed the destruction of the brush or forests on the mountains of this district. The first—production of torrential action from such denuded water-sheds. Great numbers of these cases have been noted where the rain-fall has been delivered with suddenness and with great volume, together with a large amount of débris, sand, bowlders, and gravel, from burned-off places. The results have been disastrous, sometimes in a small and sometimes in a large way, according to the area denuded. Some lands have been cut and gullied, others have been covered with débris and injured in this way. A number of orchards and other agricultural lands in the San Gabriel Valley have become the beds of torrents, owing to the destruction of brush on the foot-hills of the Sierra Madre Range.

"The second effect of the destruction of the mountain covering, and the consequent rapid discharge of the rain-water, has been the diminution and sometimes ex-

tire drying up of the springs and streams coming from injured water-sheds. The most notable cases of these results, easy of access and examination, are as follows:

"Fire on the Mission Cañon water-shed at Santa Barbara; subsequent destruction of the company's works situated in said cañon, and diminution of summer flow of water.

"Fire in Tejunga Cañon; subsequent injury to lands of E. L. Wicks by flood and cutting, and probable augmentation of damage by great flood of Los Angeles City in 1882 and 1883.

"Fire on the water-sheds of Soledad Cañon; subsequent destruction of bee ranches by flood, and of roadway and property of Southern Pacific Railroad. The damage to this railroad involved an interruption of travel for nearly six weeks, and in the neighborhood of $1,000,000 in money. This fire was set by stock-herders, nominally to benefit pasture.

"Edwards' fire on Precipice Cañon water-shed; subsequent diminution of summer water supply from this cañon. Destruction of brush on foot-hills on Sierra Madre Mountains near Pasadena; subsequent appearance of two torrents, which have continued to do great damage to orchards, agricultural lands, etc.

"Fires on Santa Anita, San Gabriel, Sawpit, San Dimas, and San Antonio Cañons, and in many other localities, with similar results.

"The destruction of small wood at Los Coyotes Ranch; subsequent disappearance of spring in said locality.

"For further detailed accounts see page 27, First Biennial Report of California State Board of Forestry.

"Notice may be called, in a general way, to the fact that where the rain-fall is the heaviest—say 25 inches on the steep chaparral-covered Sierra Madre Range—floods have done no damage except from burned water-sheds; while from the bare hills of the Colorado Desert, with a rain-fall of 4 or 5 inches, extensive damage is done every year or two to the only thing there to damage—the road-bed of the railway.

"The consideration of these facts makes it apparent that the brush and forest mountain lands of southern California of no direct value to agriculture, are of great indirect value to every industry in that section.

"*Extent and effect of Tree-planting.*—Tree-planting throughout this area has been carried on to a considerable extent. It has, however, been limited to the fertile valleys upon the western water-shed. In a few places on the edge of the desert, but where water has been brought down, as at Riverside, San Jacinto, Antelope Valley, etc., considerable areas have been planted to fruit trees, with forest trees as wind-breaks to protect them.

"The effect of this tree-planting has been to diminish the force of the winds. The orchards planted along the edge of the Sierra and cultivated area, planted up to and during 1880, suffered a great deal from the hot dry desert winds. I have seen the bark of the trees and the fruit frequently excoriated by the sand carried by the wind, so that the tree and fruit gave the appearance of having been subjected, on the windward side, to a sand blast. Since 1882 I have not known of anything of this kind on the westward side of the mountains.

"Another effect of the plantations has been to diminish the efficiency of the wind-mills—at Riverside, for instance,—which is a colony reclaimed from the desert and now shipping about 2,000 car-loads of product annually, the domestic water being taken by wind-mills from deep wells. When the colony was first started the wind-mills set up to pump this water did more work than was necessary. I am informed now, by some of my friends having orchards at this point, that they experienced the greatest difficulty in getting from their wind-mills a sufficient supply of water.

"The hot desert winds have been undoubtedly lessened in force in our valleys, and so also have what we call trade winds.

"This trade-wind is one which blows in the dry season from the ocean towards the desert. In some places it blew very strongly, so much so as to stunt and disfigure trees subjected to it. One of these places was the Santa Maria Valley. The settlers in this locality have planted wind-breaks of great extent, with the effect of doing away with the damage of this wind. The only place where forest culture has been undertaken to any considerable extent is in Los Angeles County. Several large plantations have been made here with a good profit to the experimenters. There has, however, been no sufficient forest work, in the proper sense of the word, to modify anything, except in a very local way.

"*Recommendations.*—A forest policy should be inaugurated to maintain the integrity of the forest-covering for the purpose of preventing the formation of torrents or destructive floods, and the protection of the permanent water supplies of the country.

"Wherever the desert lands have been brought under water; that is, had water brought so that they could be irrigated, as at the great and productive colony of Riverside, they have proved very fertile. If the policy be adopted by the Government of making valuable and habitable vast extents of the Mojave and Colorado Deserts by irrigation, the storage of water for this purpose would necessarily be in

the high ranges receiving considerable rain-fall. If the brush covering, or forests, be burned or destroyed on the water-sheds furnishing the supply of such reservoirs, the unimpeded rain-fall flowing off more rapidly must carry great quantities of débris, sand, gravel, etc., which will destroy the efficiency and value of the reservoirs by filling them up. Consequently, co-incident with the adoption of such a policy, a rational forestry system should be inaugurated." (Abbot Kinney.)

Mr. Fernon also called attention to the annual report for 1889 of the forestry division on "The Forest Conditions of the Rocky Mountains," etc. He filed a printed copy of the same. It is already printed for the Department of Agriculture.

STATEMENT OF C. V. RILEY, ENTOMOLOGIST DEPARTMENT OF AGRICULTURE.

The CHAIRMAN. Please state your position.

Mr. RILEY. I am Entomologist of the Department of Agriculture.

The CHAIRMAN. On what subject is the paper which you submit?

Mr. RILEY. On the general subject of the importance of extending any system that may be adopted of irrigation from the entomological stand-point; that is, with the view of checking the ravages of some of those insect pests that do so much damage in the West, particularly the Rocky Mountain locust, or so-called grasshopper, and chinch-bug.

As these matters have been published and the recommendations of the Entomological Commission, which had the study of the grasshopper question in charge, are on record, I have referred to those recommendations. I will only say in a few words that there is nothing concrete to say to you except this, that we dealt with the Northwestern region. Practically these facts stand out boldly, that the native home of that grievous pest is this extreme Northwest region, the permanent breeding ground of that insect.

The only way in which it will be possible in time to overcome this pest is by an extension of settlement. The mode of irrigation that will enable you to extend your settlements is the mode I believe to be the feasible mode. So far as this country is concerned, we have simply suggested some system which must be taken up by the Government, because it is beyond the power of private enterprise—some system that will enable you to save in reservoirs the immense waste of waters from the chief arteries, like the Missouri, and the waste that comes from the overflow system, by building reservoirs that shall hold it.

The CHAIRMAN. We have considered that subject very much, but after we shall have accomplished all that we can accomplish in regulating the irrigation of the arid lands there will be a large area of land above the lines of the ditches that will be liable to be the breeding ground still of those insects.

Mr. RILEY. What is called the permanent region, which is essentially the arid region, trenches upon the subarid region. I have not the time, even if I had the ability, to discuss the points that should be brought up for consideration before you as to what the irrigation system should be. It should of course embrace the underground currents as well as others.

We made a suggestion ten years ago—now somewhat antiquated perhaps—which was that the Government should donate a strip of land running from the Black Hills to the northwest line—right to the boundary—to any company that would undertake to develop a system of irrigation and improvement; believing that that region once thoroughly developed, these pests would be got rid of. If you can retain suffi-

cient water to enable you to cultivate trees or any other crop in this settlement you would at once solve the question of the vast devastating swarms of grasshoppers.

I believe that Government aid should come in only where private enterprise will end. In all valleys which give promise of development I think we can depend on private enterprise developing as much as possible; but Government aid should come in when that will end.

That is why I think Government service should consist largely, as has been well said, of locating possible reservoirs, indicating what they will cost and availing ourselves of the large bodies of water that are annually sent into the sea during the high tide seasons.

The CHAIRMAN. Then your idea is that as the country west of the great plains is developed and brought into cultivation the home of the grasshopper will be limited gradually or cease to exist?

Mr. RILEY. Without question, in proportion as settlements extend. Anything that will permit settlers to live and cultivate the soil, in proportion as that settlement encroaches on the arid land we shall have less and less of those grievous periodical devastations of the grasshopper.

Mr. Riley submitted the following:

REPORT TO THE SECRETARY BY THE DIVISION OF ENTOMOLOGY IN REPLY TO INQUIRIES OF THE COMMITTEE.

The question of the proposed reclamation of the arid lands of the West by irrigation is of great importance from the entomological stand-point, and particularly in view of its influence upon the destructive appearances of the Rocky Mountain locust, or Western grasshopper, which at irregular intervals has greatly damaged the agriculture of certain of our Western States and Territories. The last important invasion of this pest occurred during the years 1874, 1875, and 1876, and the devastation which it occasioned at that time is so fresh in the minds of all as to require no elaboration of the importance of the subject. The roports of the United States Entomological Commission, an organization founded in March, 1877, and composed of Profs. C. V. Riley, A. S. Packard, and Cyrus Thomas, consider the question of the influence of irrigation of a large extent of the arid territory upon the increase of this pest, and from the first report of this Commission, published during the year 1878, and the second report, published in 1880, can be drawn a complete summary of the writings on this subject and the views in full of the Commission. Copies of these reports would accompany this statement, but they have been long out of print. They may be found, however, in the library of the Geological Survey.

One of the important results arrived at is the conclusion that an extensive system of irrigation upon a scale of greater magnitude than any which can be undertaken by a pioneer population will be not only necessary to the carrying on of agricultural operations within the belt of territory mapped out as the permanent breeding ground of the locust, but that the prime result of such an introduction of diversified agriculture into these regions will be the abolishing of the conditions necessary to a permanent reproduction of the species, and a consequent reduction to a minimum of the danger of the appearance of destructive migratory swarms. The one fact, that according to the careful statistics gathered by the Commission the loss from this pest during the years 1874 to 1877 amounted to upwards of $200,000,000, is a mighty argument for the expenditure of the sums which it is proposed to devote to the purpose which Senator Stewart's committee has now under investigation. The words which follow are quoted from the first report above referred to:

"It is evident, therefore, that the final and complete solution of the locust problem depends to a certain extent upon the possibility of modifying, to some degree at least, the aridity of the great plains of the Northwest, which undoubtedly form the native breeding grounds of these insects.

"By most persons this will be considered equivalent to saying that the locust problem will never be solved. It would scarcely be proper for us here to enter into a discussion of the question of the possibility of modifying the condition of the dry area, but we can not refrain from placing upon record our protest against any such conclusion as this. That man, with a mind that can bring art, science, and mechanics to the perfection now visible on every hand, must be forever unable to convert the

desert into fertile fields or to redeem the waste places of earth we can not believe, unless we are shown that the moisture which once supplied these areas has forever taken its departure from our globe.

"To what extent these dry areas of the West can be supplied with water and rendered fertile must be determined by those who are proficient in this particular branch of science; but that large sections can be redeemed by proper efforts, if made on a scale of sufficient magnitude, we have no doubt.

"By utilizing all the water that flows down from the mountains for the purposes of irrigation; by collecting in reservoirs the winter supply and distributing it in the growing season, a very large section of these plains might be brought under cultivation, and extensive forests grown where now the surface is naked and barren. Every field brought into cultivation, every grove planted, is just so far a step toward the ultimate solution of the locust problem; and the nearer these can be brought to their native home the more effectual will they be in rooting them out. If extensive efforts in this direction were made in British America, north of Montana, also in eastern Montana, western Dakota, and the regions around the Black Hills, it would not only be of immense benefit in supplying new agricultural fields for emigrants but solve the locust problem. It would also be a most effectual method of settling the Indian question in this region. Just what can be done in the way of redeeming these areas we can not say, but when their settlement depends upon it, and the welfare of a much larger area south and west also depends upon it, certainly the question is worthy of consideration by our national authorities.

"The day is not far distant when our National Government will be compelled to meet this important question and to test the ability of man to accomplish the work.

"The progress of settlement westward must necessarily be slow when it, as is now beginning to be the case, impinges upon the sterile area; it can only push onward when the front line is backed by a dense population and farms studded with groves. It is possible that if there were no other impediments to overcome than this sterility, formidable as it is, the gradual filling up of the border area with an active population would modify the conditions sufficiently, at least, to allow the pushing into and redemption of a belt of considerable breadth. But when to this difficulty is added the devouring locust the hope of success is greatly diminished." (First Report U. S. Entomological Commission, pp. 126–127.)

Further quotations from this and the second and third reports of the Commission are appended and should be studied to enable a full understanding of the probable influence of such a course as the Commission has recommended. The desirability of forest planting is frequently mentioned in these extracts and the influence of such a move in altering for the better the conditions of the permanent breeding grounds of the locust can not be overestimated.

The effect of irrigation upon the Rocky Mountain locust dwarfs into comparative insignificance anything which may be said concerning its influence on other destructive species, yet there are many forms which depend for their existence and multiplication upon a dry climate and which a thorough system of irrigation would render comparatively harmless.

This has been recognized by the prominent writers upon economic entomology, and I may quote the words of my chief, Professor Riley, as follows:

"I have repeatedly laid stress in my writings on the importance of irrigation in combating several of our worst insect enemies, and aside from its benefits in this direction every recurrence of a droughty year convinces me of its importance as a means of guarding against failure of crops from excessive drought. I am glad to know that many farmers, and especially small fruit-growers in the vicinity of New York, are preparing in one way or another for irrigation whenever it becomes necessary, and I was pleased to hear Dr. Hexamer, at the late meeting of the American Pomological Society, urge a general system of irrigation as the most profitable investment the cultivator can make in a climate subject to such periods of drought as ours is known to be."

Perhaps the most striking example among this class of insects is the chinch-bug—a species which damages certain cereal crops to the extent of upwards of $50,000,000 in years of abundance. This insect is directly influenced by moisture and seldom occurs in numbers in the more eastern States, except after two or more successive seasons of drought. After a year of successive multiplication these insects will often be found to have hibernated in immense numbers, and it is a well known fact that heavy rainfall the succeeding spring will destroy them almost completely. This being the case, the artificial system of irrigation will enable the agriculturist to hold this insect completely in check, and such a system as it is proposed to introduce in the West will render the grain-growers of the reclaimed regions independent of the damage which may be done by this insect and will enable them to compete on most advantageous terms with the grain-growers of the more eastern localities whose crops are occasionally subject to almost total loss by this insect enemy. I again quote from Professor Riley:

"Irrigation, where it can be applied—and it can be in much of the territory in the vicinity of the Rocky Mountains where the insect commits sad havoc, as with a little effort in many regions in the heart of the Mississippi Valley—is the only real available practical remedy after the bugs have commenced multiplying in the spring. I wish to lay particular stress upon this matter of irrigation, believing as I do that it is an effectual remedy against this pest, and that by overflowing a grain field for a couple of days or by saturating the ground after as many more in the month of May, we may effectually prevent its subsequent injuries." (Seventh Rept. Ins. Mo.)

We may mention also the case of the grape-vine phylloxera and may again quote from Professor Riley:

"Submersion, where practicable, and where it is total and sufficiently prolonged is a perfect remedy. This is what even the closest student might expect, as he finds that excessive moisture is very disastrous to the lice. M. Louis Faucon, of Graveson (Bouche du Rhône), France, has abundantly proved its efficacy, and has, by means of it, totally annihilated the insect in his vineyard which was suffering from it four years ago. From his experience we may draw the following conclusions:

"(1) The best season to submerge is in autumn (September and October, when the lice are yet active and the vines have ceased growing. Submergence for twenty-five to thirty days at this season will generally rout the lice. (2) A submergence of forty to fifty days, in winter, is required, and even where the water is allowed to remain during the whole season, the vineyard does not suffer. (I should consider this very doubtful.) (3) A vineyard should never be inundated for a longer period than two days in summer, or during growth; and though these brief inundations at that season affect only the few lice near the surface, and are by no means essential, they are nevertheless important auxiliaries to the more thorough fall or winter submersion, as they destroy the few lice which are always invading a vineyard in infested districts. These summer inundations will be necessary only after the winged insects begin to appear; and three or four, each lasting less than two days, made between the middle of July and the fall of the leaf, will effect the end desired. (4) An embankment should be made around the vineyard in order that the water may evaporate and permeate the earth, but not run off and carry away any nutritive properties of the soil.

"The varied success which has attended the different attempts to rout the enemy by inundation, is owing to the lack of thoroughness in many of them. The ground must be thoroughly soaked for a sufficient length of time. Temporary irrigation does not accomplish the end for the reason that it does not reach all the lice, and does not break up the numerous air bubbles which form in the soil and prevent the drowning of many of the insects." (Sixth Rept. Ins. Mo.)

Too much in fact can not be said of the advantages of a system of irrigation in fighting many insect pests. A good instance occurred in our experience in the spring of 1879 when the Army worm appeared in great force upon a large grass plantation near Portsmouth, Va. The plantation was divided into sections by irrigating ditches and it was only necessary to turn on the water to isolate a badly infested section and to devote it by rolling, fire, or some other means of destruction preventing ready spread of worms to other sections. In the same way rice planters have a ready means of fighting insect pests at hand.

Other insects might be particularized, but the general statement that from the stand-point of the economic entomologist irrigation in general is a great help in fighting insect pests, and from the marked illustration of the great good to be accomplished by the reclamation of the arid regions in connection with the damage done by the Rocky Mountain locust, it will probably be considered that further elaboration will be unnecessary.

Respectfully submitted, May 13, 1889.

L. O. HOWARD,
Acting Entomologist

EXTRACTS FROM THE REPORTS OF THE UNITED STATES ENTOMOLOGICAL COMMISSION.

In the permanent region which embraces the Rocky Mountain plateau and the bordering plains from the middle of Colorado northward the rain-fall is insufficient for agricultural purposes, and hence irrigation has to be resorted to. In the temporary region this is unnecessary. The plains and plateaus of the permanent region are to a large extent distinguished by the presence of *Artemisia*, Chenopodiaceous plants, and what is usually termed "bunch-grass;" in short, by all the characteristics of a drier climate. One other peculiarity which should not be overlooked appears to mark roughly the southern boundary of the permanent home of the Rocky Mountain locust, and that is the isothermal curve or line of the fiftieth degree of mean annual temperature, which also corresponds very nearly with the isothermal curve or line of summer

temperature of seventy degrees. But this applies only to that portion of the region which extends upon the plains east of the mountains.

If any practical means of exterminating the locusts in this permanent region could be devised the whole locust problem could be solved, and nothing further would be necessary. But when we take into consideration the vast extent of this area, and the fact that a very large portion of it can not be brought under cultivation without a material change in the climatic conditions, there appears but little hope that such a means of actual extermination will ever be devised, however much we may hope to check the injurious increase of the pest by the means recommended in the concluding chapter of this report. Our discussion of the future prospects of this region in reference to agriculture may as well, therefore, proceed on this basis. (Second Report United States Entomological Commission, pp. 15–16.)

* * * * * * *

A careful investigation of this subject for several years and repeated visits in person to this region have served to convince us that, with the advantages afforded by the system of irrigation necessarily adopted, there is no reason why the agricultural area lying along the east flank of the range should suffer any more from these pests than portions of the temporary regions. (*Ibid.*, p. 19.)

* * * * * * *

This agricultural belt, extending from Colorado into British America, is partly along the margin of and partly in the very heart of the permanent breeding-grounds where the swarms that invade the temporary region originate. It follows, then, as a natural consequence, that just so far as the numbers are lessened by the operations in this section, just so far will the agriculturists of the temporary region be benefited, and, as we will hereafter see, like operations in the latter region will benefit those in the permanent region. We are fully aware of the fact that the part of this vast region which can be irrigated and cultivated is small in comparison with the whole area which forms the native home of the species, but, fortunately, in one respect this cultivated belt occupies in part, at least, the point of departure of the swarms which invade the temporary region. This fact, therefore, renders it more important that it be occupied by an agricultural population.

Although we have admitted that we are unable to present any plan of exterminating the locusts that holds out sufficient promise of success to justify the General Government in undertaking it, it does not necessarily follow that there is no plan of modifying the evil which the Government would not be justified in undertaking. On the contrary, if the views we have advanced be correct, they suggest a means by which the General Government might greatly aid in bringing about the desired result; and, fortunately, the result would be beneficial even should we be mistaken in the opinions advanced.

As will be seen by what has been stated, the great desideratum is to settle the cultivable belt alluded to as rapidly as possible with an agricultural population. Wherever valuable and permanent mines are discovered in the neighboring mountains, the arable areas in the vicinity will be taken up and cultivated to an extent at least sufficient to supply the demand for agricultural products, as in parts of Colorado. But there are large sections where no such influence will be brought to bear, and this is the case along that portion of the belt where the agricultural population is most needed for the purpose mentioned.

An examination of map No. 1, in our first report, will show that a comparatively limited belt in central Montana, extending from the Big Horn Mountains northwest to the British line, a little west of Cypress Hill, forms the turning-point of the locust movements. Without now repeating the data which may be found in that report, we may summarize it by saying that from this region a large portion of the swarms come which visit Dakota, Minnesota, Nebraska, and Kansas; from this area also proceed a large portion of the swarms that move southwest into Idaho and Utah. This appears to be the point to which most of the returning swarms from the temporary region direct their flight.

That there are other areas in the permanent region which appear to be special breeding-grounds, as points of departure, is certainly true, but none to such an extent as this, and none affecting an agricultural area bearing any comparison with the area affected by the locust swarms originating in this belt.

Even should it be shown by subsequent investigations that as a rule the swarms falling on the temporary regions come from intermediate points, as central and southern Dakota and northwestern Nebraska, the facts already ascertained warrant us in asserting that, as a very general rule, they originate in the belt mentioned.

It is evident, therefore, that if any method can be devised by which an agricultural (not pastoral) population can be thrown into this belt, it will form one of the best possible means of modifying the evil. If they can be effectually distributed in this area the result will be of immense value to the agricultural interests of Dakota, Minnesota, Nebraska, Iowa, and Kansas, in fact of the entire temporary region. We

do not pretend that it will wholly relieve this area from locust invasions, but it will very materially lessen their extent and injury.

In order to carry on agricultural operations to any great extent in this belt, an extensive system of irrigation will be absolutely necessary. It will have to be on a scale of greater magnitude than any that will be undertaken by a pioneer population. We doubt the propriety of the General Government undertaking such a work directly, if it is possible to accomplish it in any other way. This, we think, may possibly be done by giving the land for this purpose. We are fully aware of the opposition at present to the Government's donating any more of the public land, but the circumstances of this case bring it out of the general rule. If donating the entire body of public land in the belt described would suffice to settle it with an agricultural population, not only would the very purpose for which it is held be accomplished, but, if our views are correct, the result would be of immense benefit to the border States.

We therefore suggest the following as probably the most feasible plan of accomplishing the desired end: Let the United States donate a belt of 50 or 60 miles in width, running from the Black Hills west-northwest, so as to strike the Yellowstone River a short distance above the mouth of the Big Horn River; from thence north-northwest, by way of Fort Shaw or the mouth of Sun River, in the direction of Fort Hamilton, in British America; this to be granted on condition that the company to which said land is granted shall, within a given time, construct a railroad from the Black Hills along the line designated, to the international boundary, shall undertake and carry out, to an extent to be designated, a system of irrigation, and shall equip and keep in operation said road for a certain number of years.

Whether such grant will be sufficient inducement for any competent company to undertake the work specified is probably the chief difficulty in the way of successfully carrying out this plan. On this point we do not feel qualified to express an opinion. That such a road, starting from the Black Hills, if once built, would soon be connected southward and eastward with other roads, can not be doubted. That it would be the best possible means of bringing an agricultural population into this belt can not be doubted. It would also be an important factor in settling the trouble some Indian problem in this section of the West.

If the plan should be adopted it might be well to colonize, if possible, with Russian peasants who are accustomed to fighting locusts.

The advantage to be derived from this plan consists chiefly in the fact that it is possible to destroy the young to a very large extent by the use of the proper means. If this is done in the very heart of their breeding-grounds, it greatly lessens the numbers that will migrate. Not only does it prevent the number destroyed from migrating, but for each one killed, so to speak, an entire family brood of the next or migrating generation is destroyed. In other words, the destruction of thousands there would be as effectual as destroying millions of the migrating swarms. The means of destroying the young, as before stated, can be made more effectual in the sections where irrigation is carried on than where it is not.

As shown in our first report, the destruction of the young locusts bred in the temporary region from the invading hordes not only gives immediate relief, but also tends to postpone future invasions by so lessening the numbers in the returning swarms that a longer time is required for development. With an agricultural population in the area designated, the work of destruction would then be carried on at each end of their migratory route.

Here we may also remark that the present idea of making that section of our country peculiarly pastoral area, while doubtless profitable to the present and for two or three generations to come, will in the end entail hardships upon those to follow. It can no longer be doubted that while the destruction of forests was the chief agency, yet the pastoral habit of the people of Western Asia and other oriental countries, once so fertile but now so barren, was one important factor in producing the present dry and barren condition of those countries. No country in the interior of a continent, unless supplied with numerous lakes or numerous and permanent rivers, can remain permanently fertile and productive if given up largely to pasturage of sheep, goats, and cattle without cultivation. The rapid destruction of mountain forests and pasturing their slopes and bordering plains will most certainly have a tendency to render that portion of our country more dry and barren.

Unless, therefore, our Government adopts some policy by which an agricultural population can be thrown into that area the day will most assuredly come when it will be as barren and desolate as the plains of Arabia. The development of the locusts is but an incident of the change from a former condition of abundant moisture to the present dry one. But this branch of the subject we propose to omit at present.

It will be seen, therefore, by the foregoing that we think it is possible to modify to a very large extent the operations of the locusts so far as these relate to the area

along the east flank of the mountains, and that the General Government may, without any very great expense, very greatly assist in the work. (*Ibid.* pp. 19–22.)

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This certainly shows a very moderate climate for this northern latitude. Wheat, oats, rye, and barley grow well, and Indian corn is also raised without difficulty and produces good crops. Such fruits as apples, plums, cherries, currants, raspberries, and gooseberries may be grown and matured here, the climate presenting no serious obstacles.

The amount of land that can be brought under cultivation depends wholly upon the amount of water that can be obtained for irrigation. If the plan for making reservoirs for preserving the winter supply should ever be adopted, the breadth of the agricultural belt would be very largely increased, and this would be doubly beneficial in assisting to destroy the locusts and tending to increase the moisture in the atmosphere by forming a larger evaporating surface. The growth of trees and shrubbery around these reservoirs would also be beneficial in the same direction.

But experience in the settlement of these mountain regions and Western Territories shows that no such extensive works will, or in fact can be, undertaken by a pioneer agricultural population. Some efficient aid of some kind must be given if such a scheme is ever carried into effect, and if the land itself will do this, the Government will act wisely in giving it for this purpose. (*Ibid.*, p. 23.).

* * * * * * *

As shown by our first report, the region around Salt Lake is subject to repeated locust invasions from the north, apparently the resulting broods of the swarms that originate in that portion of Montana of which we have been speaking, and which, pouring over the mountain pass at the head of Jefferson River, move down Snake River Valley.

If the scheme we have suggested should be carried out and should prove beneficial in reference to the eastern area, it would have, to some extent at least, a like effect as to this section. If it is possible to establish and maintain an agricultural population in the Upper Snake River Valley, this would have a strong tendency to modify the evil. But the present barren aspect of this region would seem to forbid any hopes of ever accomplishing this desired end. Still there appears to be one possible means of bringing this about, at least to a limited extent. The demand of trade will doubtless complete the railroad already started in that direction, which is one step toward the desired end, but something more is required in this case.

Snake River affords a large body of water which, if properly utilized, would irrigate a large breadth of land, and, notwithstanding the barren appearance of the soil, is really fertile when irrigated. It is possible, with a moderate expense, to throw dams across this stream at certain favorable spots, and by this means to spread the water over the adjoining plains. A work of this kind would, of course, have to be done by the General Government. The feasibility of this project could easily be ascertained by an officer of the Engineer Corps of the Army; and as this is on the line of the chief intermountane thoroughfare and also of the locust invasions of this region, the subject is certainly worthy of the attention of the Government.

As will be seen by what we have presented on this subject, the philosophy of our plan for modifying the evil is to place an agricultural population in the very home of the species, which from necessity would be compelled to wage a constant warfare against them.

By stirring the soil their nests would be disturbed; by fighting the young their numbers would be diminished; and as irrigation would be necessary the effect of dry seasons on the crops would not be felt as in the temporary region. The possibility of inundating to a considerable extent their egg deposits by the winter supply of water would tend to diminish their numbers. The fact that their breeding-grounds are chiefly in the limited agricultural areas is also another argument in favor of the plan.

That large areas would be left where locusts breed and pour down on the nearest cultivated areas, as in western Colorado, is certainly true; but this does not lessen the value of the plan proposed, nor is it a reason why it should not be put into operation. (*Ibid.*, pp. 24, 25.)

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Naturally with the increase in the number of farms and advance of the settlements upon the frontier the devastation by locusts will be felt less. They will divide their ravages among more farmers, and hence none will feel the losses nearly as much as did those who were isolated from their neighbors during past invasions. Thinly-settled districts suffered much more than those which were more thickly settled; and those lying out upon the prairie than those adjoining and interspersed with groves. During these invasions there was no year but in which a portion of the crops was saved and harvested by the farmers of the extreme eastern portion of Nebraska and other sections of country that were comparatively thickly settled, and that were situated near some natural timber-belt and interspersed with planted groves; while, on the contrary, those that were far away from these natural and artificial groves, and

thinly settled, were entirely devastated by the hordes of ravenous insects. Hence we are compelled to acknowledge that the settling of a country in which the settlers are tree-planters has a tendency to diminish the ratio of locust injury.

Tree-planting is not only a matter of great importance to the inhabitants of a country like ours in supplying a much-needed material for fuel during our severe winters, when at times it is impossible to obtain coal—either from the failure of a sufficient supply at the mines, or from the impracticability of reaching towns where it can be obtained—but it is also of untold benefit as a moderator of climatic extremes. By planting trees throughout the Temporary Region wherever they will grow, in time the area in which the locust is capable of continuing its existence but two or at most three generations, without having recourse to the arid regions hitherto referred to as the permanent breeding-grounds, will be increased. Aside from the greater amount of humidity that would naturally follow tree-planting, the spread of locust-feeding birds would be correspondingly increased, and the amount of good thus accomplished could hardly be estimated. As long, however, as there are no retreats or building places in which these little feathered friends of ours can rear there little ones, we need not look for their aid in fighting insect enemies.

The increase in the number of settlers would also add to the number of individuals to fight the locusts, and hence help to increase the sum total of their dead and to diminish the swarms otherwise remaining to do damage and to increase at the ratio of a hundred-fold. (Third Report U. S. Entomological Commission, pp. 44, 45.)

Mr. WILLITS. Dr. Vesey was to have been here, and he had a statement, too, but I will send the paper up.* Dr. Merriam is here, and I would like the committee to hear from him.

The CHAIRMAN. We will hear from Dr. Merriam.

STATEMENT OF C. HART MERRIAM, ORNITHOLOGIST.

The CHAIRMAN. What is your position?

Mr. MERRIAM. I am chief of Division of Ornithology and Mammalogy of the Department of Agriculture.

I was desired by Secretary Willits to come here and speak of the availability of certain areas of the arid lands for the introduction of certain agricultural crops and certain birds and animals which are injurious or beneficial to mankind.

In the southern part of the arid lands camels have been already introduced. Many years ago the War Department introduced camels in this country, and herds are now supposed to be living in western Texas and in Arizona.

Nothing has been done to utilize them as beasts of burden, but there can be no doubt that enormous good and enormous value would result to the arid land by the proper introduction and domestication of the camels of those regions. The herds now roaming wild over considerable areas in the arid lands could be put to very useful service. Our arid lands extend from the Mexican border to the plains of the Saskatchewan and embrace a number of distinct climates. Each of those climates is adapted to the wants of certain classifications of animal and vegetable life. We find that we are able to subdivide the West into a number of areas which we call life areas, because each of those areas possesses associations of plants and mammals, birds, reptiles, insects, etc., that are not found in continuous areas, and we find in applying agriculture to those areas that the same areas that support definite associations of plants and animals in a wild state are adapted by nature to definite kinds of agricultural crops and to definite breeds of animals.

This is a subject that has been almost entirely overlooked in studying the question of the relation of climatology, particularly of temperature and humidity, to the relations of life; it is one of the utmost importance. I think it is not saying too much to state that agricultural science in this country is going to be completely revolutionized whenever it is studied in connection with the natural life areas and the climatology of the country. Experimental agriculture will cease.

* Dr. Vasey's paper was not received.

The CHAIRMAN. Have you to any considerable extent classified the sections, and the animals belonging to them?

Mr. MERRIAM. I have been engaged in that work for the last four or five years, and have a number of maps now in progress of the whole United States, showing the primary, secondary, and tertiary life areas in which the country is subdivisible. That is the work in which I am now engaged.

The CHAIRMAN. That would not come within the scope of our report; but I agree with you that it is a very important subject of inquiry, if you can ascertain as to each region when developed what will be the products, and what animals will thrive there, and what will be suitable for them for food. That information will be most valuable to settlers in order to inform them what animals they may keep.

Adjourned.

FIFTH DAY'S SESSION.

WASHINGTON, D. C., *March* 13, 1890.

The committee met pursuant to adjournment.

Present: Mr. Stewart (chairman), Mr. Moody, Mr. Casey, Mr. Reagan, and Mr. Jones, of Arkansas.

STATEMENT OF CAPT. C. E. DUTTON, U. S. ARMY, CHIEF ENGINEER U. S. IRRIGATION SURVEY.

The CHAIRMAN. Captain, you are an officer of the Army?

Captain DUTTON. I am, sir.

The CHAIRMAN. And assigned to the Geological Survey?

Captain DUTTON. Yes, sir.

The CHAIRMAN. State what connection you have had with the Irrigation Survey, what your position has been in that survey, etc.

Captain DUTTON. When the survey was first authorized by law Major Powell requested me to take charge of the field-work of the engineering and hydrographic parties. The details of the field-work were drawn up and submitted by myself to the director, and were approved by him, and, since the passage of the law and since the time when the appropriation became available, I have had charge of the engineering and hydrographic work.

The CHAIRMAN. Has there been any other work than hydrographic and engineering work done in connection with the survey?

Captain DUTTON. Within the limits of the appropriation?

The CHAIRMAN. Yes.

Captain DUTTON. Yes, sir. There has been a large amount of topographic work, with which I have had nothing to do.

The CHAIRMAN. Of the $350,000 that have been appropriated how much has been expended for hydrographic and engineering work, and how much for topographic work?

Captain DUTTON. Out of the first appropriation—you will remember there were two——

The CHAIRMAN. (Interposing.) There were two.

Captain DUTTON. Out of the first appropriation of $100,000 $36,000 were allotted for the work under my charge.

The CHAIRMAN. The engineering and hydrographic work?

Captain DUTTON. Yes, sir; there was a contingent fund reserved for expenditure under the immediate charge of the director, for office expen

ses, and for special expenses which could not be foreseen in the original estimates, and also to be a kind of insurance fund against any deviation which might compel us to exceed this allotment or else sacrifice valuable work. The amount of that, I think, was $6,000. The remainder of the $100,000, that is, $58,000, I understand was applied to topography.

The CHAIRMAN. As regards the second appropriation?

Captain DUTTON. As regards the second appropriation, the original allotment to the work under my charge, that is, the engineering and hydrographic work, was $110,000. There was a contingent fund of $20,000, and $120,000 was allotted to the topographic work.

The CHAIRMAN. Has all of that appropriation been expended?

Captain DUTTON. The last appropriation?

The CHAIRMAN. Yes, sir.

Captain DUTTON. No, sir.

The CHAIRMAN. How much has been expended of what was allotted to the hydrographic and engineering work?

Captain DUTTON. I can not give the exact figures, but I can approximate to them off-hand. There still remains available for expenditure about $29,000, reckoning from the 1st of March, for the work under my charge. As regards the work in the topographic branch I am unable to say how much remains unexpended.

The CHAIRMAN. The $29,000 will be expended as you go along, in completing the work?

Captain DUTTON. Yes, sir; to complete the office work, and more especially to keep the hydrographic work going, which it is absolutely necessary to maintain constantly, without any intermission, in the field, that is, to a certain extent. The great bulk of the remainder now unexpended is being applied to the hydrographic work.

Senator REAGAN. That is, the remainder of the $120,000.

Captain DUTTON. The remainder of the $110,000. That is a class of work which requires more constant and steady expenditure than the engineering work, because it is necessary to keep up stations in the field constantly.

The CHAIRMAN. Is there any connection, in practical operations, between the topographic work and the engineering work; how do they co-operate, if at all?

Captain DUTTON. There is a certain amount of general utility for engineering and hydrographic purposes to be found in a good topographic survey. According to my understanding there is no absolute dependence upon topographic work for the proper conduct of good engineering and hydrographic work; in other words, an engineering and hydrographic survey could be conducted with good results, meeting the purposes and requirements of the law, if there were no topographic survey. Our results probably would be in some measure better spread upon the record, better published, and made more intelligible, if we had good topographic work in advance, and good topographic work would undoubtedly be accompanied by certain conveniences; but the question of necessity is one of degree.

Senator REAGAN. I do not understand these things very well. Will you define the difference between what you call engineering and hydrographic work and topographic work, so we can see what the differences between the two classes is?

Captain DUTTON. In order to carry out the purposes of this law, as it has been understood in the survey, and in order to meet all the special requirements of the law, which provides for investigating the extent

to which arid lands can be redeemed by irrigation, one of the first things which is necessary to know is the available water supply, and not merely the water supply, but also what the water can do—how much a given quantity of water can do, both in general and in particular—as a general rule and in particular cases. It is therefore necessary to make what we call a hydrographic investigation to know how much water we have at our command. The hydrographic work has been understood to include the measurement of the waters flowing in the streams, and to ascertain the rate or distribution of the flow of streams during different parts of the year, to know when the waters are at a maximum and when at a minimum. It is also necessary to know what we term the "duty" of the water, to know how much land the water can irrigate, and if, as is actually the case, it varies from place to place, to know the causes upon which that variation depends—what influences the duty of the water.

There is one other very important matter in this connection which it is necessary to investigate, and that is the subject of evaporation, which becomes a highly important one in reservoirs, and especially in the largest reservoirs, for reasons that will readily suggest themselves to you. A large reservoir is generally a shallow one, and a very large basin can not under any ordinary circumstances receive a sufficient quantity of water to cause a great rise and fall in that reservoir. Now, if the proportion of evaporation to the amount of available inflow of a reservoir is very large it becomes a very important question to know how much that evaporation is, and there are very many cases where the value of a reservoir will turn upon the ratio which exists between evaporation and inflow. Therefore it is necessary to make an accurate investigation of the rate of evaporation. There is still one other question which we consider—a hydrographic one—which we have not as yet taken up systematically, but have only investigated in one or two localities, and that is the quantity of sediment which the streams transport. That becomes a matter of very great importance in determining the life of a reservoir, how long it will take to fill it. These are practical matters which the hydrographic service is expected to investigate. The engineering survey investigates questions of a different character, but into the investigation of the engineering survey the hydrographic survey enters as an important factor. The engineering survey is required to first investigate the possibilities of diverting water from streams, storing water, and the amount of land which can be irrigated by works of a specific character. I think it will appear quite clearly that if we are to obtain the information as to the amount of land which is susceptible of being irrigated we must have for each locality and each district some definite idea of the kind and the extent of the works which are to irrigate them. Therefore the engineering survey is required to form some definite project of works for the irrigation of each district. Their instructions have been to endeavor to select the best. I can perhaps convey to you that idea more forcibly by reading to you a portion of the instructions which were given early in this investigation to some of the engineers:

I desire herewith to place before you certain governing considerations of a general character with reference to the surveys you are expected to make and to the results you are expected to accomplish. In each hydrographic basin it is desired to take the problem; what are the available sources of water supply, and by what means the water may be most fully utilized? A hydrographic basin may mean the water-shed of a large stream or of a small one, or a great river or one of its tributaries; but whether it means a trunk stream or a branch of it (a question to be decided by the engineer), it is assumed that there is some form of development and construction of the work

which may be judged to be the best that the engineer can devise. The engineers should take no account of works which are already constructed; nor should their judgment be swayed by any opinion on their part as to what works private enterprises and capital are likely to undertake in the next few years. They should rather address themselves to the question already propounded; what is the best system, the one which will utilize the greatest amount of water and produce the greatest amount of irrigation? It is not forgotten that as a practical matter irrigation development in each district starts with a small beginning, with works proportional to that beginning; that it advances through successive stages, by more costly works superseding the primitive ones. But of these the engineer should take no account. His project should embrace what is in his judgment the best system, irrespective of what is or actually may be constructed. At the same time his project should be a practical one, involving no extravagances of engineering, nor transcending the possibilities of attainment, or of maintenance after attainment. The plans should also have a certain unity, and should contemplate a single system of works for each irrigation district. If both reservoirs and canals are required, the reservoirs should be, if possible, projected as adjuncts of the canals. No doubt it will happen sometimes that the rivers alone are more than sufficient for the available land, as in the northernmost States and Territories, or that reservoirs alone are possible, as in parts of the southernmost Territories; but still, even in such cases, unity of plan should, so far as practicable, be kept in view. Engineers should seek to minimize the extension of their projects of distributive works by which water is taken from canals and reservoirs and put upon the land. With a given high line canal it will generally be possible to propose many ways of distributing its water, but the distributive system will in other cases probably be of a distinctive character, forming a vital part of the entire project, and its development in the project will then be necessary.

This instruction was deemed necessary in order to meet the requirements of the law for investigating the extent to which the arid lands are capable of being redeemed by irrigation.

Senator REAGAN. You have stated that there would be some convenience in a topographic survey. Is not a topographic survey to some extent indispensable to this work in ascertaining the altitude of the place where you locate your reservoir, the relative altitude of the ground to be irrigated, and to run the lines of the canal?

Captain DUTTON. Yes, sir; to know the line of the canal it is necessary to have an exceedingly minute and very carefully detailed topographic survey on a very large scale. It is also very necessary to have a thorough-going survey of the reservoir site itself, and most particularly of the dam site. For this purpose a topographic survey is an absolute necessity; but in speaking I had reference to a more general topographic survey of the whole country. A topographic survey to show the lines of a canal would have to be made upon a scale never less than 1,000 feet to the inch, and is more frequently 100 or 200 feet to the inch, whereas a general topographic map of the very largest size means a survey upon a scale of about 10,000 feet to the inch; that is, our scale for engineering purposes would have to be ten, fifty, or even one hundred times as large as that of a general topographic map. And there is another point in that connection. The most important feature of an engineering survey for engineering purposes deals with the vertical element; that is, with altitudes. The horizontal elements, although important, are far less so than the vertical elements. Now, it would be impracticable to construct a topographic map, at a reasonable cost, with a degree of accuracy at all commensurate with the accuracy which is demanded by the engineering surveys of a canal, or even of a reservoir.

Senator REAGAN. Is not such a topographic survey as is being made in the country where you have been a very great convenience to the engineers when they come to arrange the details of the hydraulic part of the work?

Captain DUTTON. Yes, sir; it is a convenience; there is no question about that.

Senator REAGAN. And it is of great convenience in considering the engineering problems?

Captain DUTTON. It is a great convenience. I notice that all my engineers are calling very largely for maps, and the best maps they can get.

Senator REAGAN. Are you advised as to the extent to which the topographic surveys have been made and how near they are to completion throughout that Western country generally?

Captain DUTTON. Yes, sir; I have a pretty good knowledge of that subject. I know where they have been made and I know their general character.

Senator REAGAN. State to the committee about the extent of those surveys.

The CHAIRMAN. And also state their general character.

Captain DUTTON. Well, sir, you are aware that topographic surveys of various qualities have been going on the Western country for twenty years. They have been made by different organizations of the Government. Some have been made with much more care and much more skill than others. A very large portion of the West has already been so surveyed. There has been a topographic survey made of that portion of the State of Colorado which lies west of Denver. The entire portion of the State west of Denver was surveyed under Dr. Hayden. There has been a very large portion of New Mexico surveyed, by what we are in the habit of calling a mere reconnaissance survey, under Captain Wheeler, of the Engineers. It is on a much smaller scale and much more hurriedly done than a topographic survey, and it has but little of the vertical element in it. We do not consider it a topographic survey. But some portions of New Mexico have been surveyed by the Geological Survey, perhaps about one-fourth of the Territory. Nearly one-half of Arizona has been surveyed by the Geological Survey, that, however, being the northern portion of the Territory. About two-thirds to three-fourths of Utah has been surveyed by the Geological Survey. The Wheeler survey made extensive surveys in Nevada, while the Geological Survey has made none there except in the extreme western portion of the State. The Wheeler survey has made very extensive surveys in California, and the Geological Survey has followed them up with their topographic survey, which now embraces about one-fourth, perhaps one-third, of the State—a very fine map. Southwestern Oregon has been surveyed by the Geological Survey, but probably not more than one-eighth or one-tenth of the State has been surveyed.

No surveys of any kind have been made in Washington, and the Geological Survey has made no surveys in Idaho until within the last year, and very few surveys of any kind have been made there excepting in the southeasternmost portion. In Montana a survey was made by the Northern Pacific Railway, known as the Transcontinental Survey, embracing a belt of territory which was adjacent to the Northern Pacific Railroad, mostly within the limits of its land grant, and other portions have within the last three or four years been under survey by the Geological Survey. Perhaps one-fifth or one-sixth part of Montana has been surveyed. In Wyoming there has been very little topographic work done, although a survey was begun there by Dr. Hayden during the last few years of the existence of his own survey, but only a small amount of progress had been made upon it. In the States and Territories east of the one hundredth meridian, within the arid belt, the Geological Survey has been making surveys in the valley of the Arkansas River, and

still more extensive ones in the eastern portion of Kansas. It has also been making some extensive surveys in central Texas, gradually expanding its work there. That carries us into the humid region, and there has been a great deal of surveying done, of course, in the Mississippi Valley.

The CHAIRMAN. Suppose a corps of engineers, having a report of the hydrographic work, so that they would have an approximate knowledge of the precipitation and evaporation, and the amount of water flowing in a stream, should go into a valley to locate a reservoir and the lines of ditches for the purpose of conveying the water to such lands as could be irrigated, how much information could they obtain from any topographical map that has been made of any portion of the country? Would they be able to rely on such a map, or would it be necessary for them to do their own work independent of that?

Captain DUTTON. The most valuable information they would get from a general topographic map would be a more accurate means of computing the area of the different water-sheds. I know of no other purpose which would be an indispensable one which would be served by such a map as that. But it becomes a matter of very grave moment to know what the water-shed is. It can be very readily ascertained by a few days' labor, or, if it is a large one, by a labor of a week or two; but as a general rule the exactions of accuracy in the size of a water-shed are not so great but what they can be made fairly and with a sufficient degree of approximation by existing data.

Senator JONES. Why do you have to know the area of a water-shed?

Captain DUTTON. In order to form some judgment in advance of the amount of water which is likely to run off from it in flood-time.

Senator JONES. Then you rely on the area of the water-shed and the average rain-fall to make your hydrographic examinations; or do you measure the streams for the purpose of making your estimates?

Captain DUTTON. Both.

Senator JONES. You do not rely on either one, absolutely?

Captain DUTTON. We place our main reliance upon stream-gauging.

Senator JONES. That is much less expensive than the other?

Captain DUTTON. No, sir; far more expensive. Stream-gauging is very expensive work.

Senator JONES. Is it more expensive than a topographic survey in ascertaining rain-fall?

Captain DUTTON. Oh, no, sir.

Senator JONES. That is the question I asked.

The CHAIRMAN. The captain meant sufficient topographic work to ascertain the area of the water-shed. That amount of topographic work would not cost as much as the topographic work.

Captain DUTTON. I think I can get a rough approximation of almost any water-shed from existing maps.

Senator JONES. Is that sufficient for practical purposes?

Captain DUTTON. Yes, sir.

The CHAIRMAN. Then there is another thing which, it seems to me, you would want to know in planning for a dam. You would not only want to know the amount of water that would come down in flood-times, approximately, but you would want to know the declivities of the water-shed, to determine how rapidly it might come down.

Captain DUTTON. Yes, sir.

The CHAIRMAN. Could the engineers in the field also make allowance for the declivities of the water-shed and judge of the probabilities of strain upon the dam, so as to make allowance for it?

Captain DUTTON. They could get some light upon that subject——

The CHAIRMAN (interposing). Would a topographic map give you some light?

Captain DUTTON. Yes, sir.

Senator JONES. Is it indispensable?

Captain DUTTON. It is not indispensable.

The CHAIRMAN. When they were making the survey could they take the altitude with sufficient accuracy to form a reasonable judgment of it?

Captain DUTTON. Yes, sir. We have no difficulty in getting altitudes in a few hours, or in a day or two at the farthest, with all the accuracy that topographers get it, because the country is now so completely covered with railroads. Topographers are obliged to rely on the railroads as a starting point for their data, and engineers can do that as well as topographers. If a case arises where the locality is very remote from a railroad he can get his altitude in precisely the same way the topographer gets his, that is, by a mercurial barometer. That is a rough way, but it gives the altitude with a fairly satisfactory degree of approximation.

Senator JONES. How long a system of observation does it require in the basin of a stream to determine the minimum water-fall and the maximum water-fall; I mean for practical purposes?

Captain DUTTON. It takes a great many years, Senator. Hydrographic observations once begun should be conducted without intermission for a long period of years, and I think that as soon as practicable the States themselves, or possibly the irrigation districts, should have that business gradually turned over to them and devolved upon them. It is their business, their province. Sooner or later all the irrigation must come——

Senator JONES (interposing). What do you think was the cause of the accident in Arizona the other day?

Captain DUTTON. An insufficient waste-weir.

Senator JONES. That is not the point I had in mind. What was the cause of the engineer making that mistake? I assume that he was competent, that he knew his business, that he knew the size of waste-weir necessary to carry off the water; but it seems that more water came down than he calculated on. Now, no matter if he had been gauging that for a long while, he could not, of course, know how much water would come down in an excessive flood unless a flood came during his observations. The question is whether you can arrive at such information by observations of the flow of the stream as to enable you to reasonably guard against accidents to works of this character, or whether it is necessary to have an examination of the country and know the area drained and the steepness of the water-shed, the amount of water that falls in an average year, and all that—whether that would be a more accurate way of guarding against destruction from floods than to depend on the gauging of the streams.

Captain DUTTON. The case of the Walnut Grove Dam, I think, brings out your suggestion very forcibly. There was a water-shed of about 325 square miles. Under any ordinary circumstances, under any ordinary rain-fall, there would have been no danger of overflowing that reservoir; but, on the other hand, those who have been acquainted with Arizona for a considerable number of years are aware that every now and then there comes an exceptional storm, and engineers who have made a special study of the subject of reservoirs and the storing of reservoirs are well aware that when the precipitation comes very rapidly and very

suddenly there is a tendency to a definite ratio between the amount of rain-fall and the amount of run-off, so that there is a possibility of making a computation of the amount of water that is likely to flow into a reservoir when the rain-fall exceeds a given amount in a given number of hours; and, now, it seems to me that the engineer who had charge of that work should have studied that problem more than he did; that he could have foreseen that there was a liability of such a rain-fall, and the precedents which have been given by the English engineers in India and by the Italian engineers in the Piedmont should have been ample to warn him of the possibility of such an accident as that.

Senator REAGAN. Was there not some defect about the masonry?

Captain DUTTON. I think not.

Senator MOODY. How large was that dam? What was the length, width, and height of it?

Captain DUTTON. The dam was 110 feet high. The bottom of it I am not accurately informed about. I have made some inquiries on the subject, but have as yet received no reply. I understand, however, that the basal dimensions were ample. It belongs to a type of dam which has become very popular in California of late, which is known as the loose-rock dam. There are some great advantages about a loose-rock dam. A leak is of very little consequence.

Senator MOODY. For what reason?

Captain DUTTON. Because the water which flows through the front of the dam flows through the back, through the interstices of the stones, and exercises no internal pressure. If water gets into a dam constructed of masonry—gets inside—it is likely to burst it by hydrostatic pressure and destroy it; but in a loose-rock dam there is no danger of that kind.

Senator MOODY. No danger of undermining?

Captain DUTTON. No danger of the undermining or bursting of the dam.

Senator MOODY. At what point from the bottom did this break occur?

Captain DUTTON. It occurred at the top, by the overflow of the dam. The waste-weir being insufficient to carry off the water, it began to overflow. If you have a dam of such great height as that and the water is permitted to overflow it, its destruction is absolutely certain.

Senator MOODY. A fall of water 110 feet makes a pressure of how much to the square inch?

Captain DUTTON. Well, it depends whether it falls unchecked or is checked.

Senator MOODY. Unchecked, as it would flow over a dam.

Captain DUTTON. The pressure would be terrible. It would be a difficult matter to compute. Its destructive power would be great.

Senator MOODY. I desire to ask a question on another branch of the subject. You say there was $110,000 of this $250,000 that was assigned to the engineering and hydrographic surveys?

Captain DUTTON. Yes, sir.

Senator MOODY. And $120,000 was assigned to the topographic survey?

Captain DUTTON. Yes, sir.

Senator MOODY. Can you state generally for what the balance of the $110,000 was expended?

Captain DUTTON. There was allotted to Montana, $9,500; to Colorado, $19,500; to New Mexico, $8,500; to Idaho, $10,000; to Nevada, $15,500; to California, $13,000; making $76,000 for engineering work.

Thirty-four thousand dollars was allotted for the hydrographic work, making $110,000.

Senator MOODY. Commencing with Montana, please state where and in what work that was expended?

Captain DUTTON. A large proportion of it was expended in making surveys of the Sun River Valley and in making reconnaissances of the Yellowstone and the Three Forks of the Upper Missouri and the country lying between the Yellowstone and the Missouri Rivers.

Senator MOODY. What practical work was done in the Sun River Valley? Were any reservoir sites selected or lines of canals or ditches run?

Captain DUTTON. There were ten reservoir sites first selected, of which one was rejected, as being impracticable. The remaining nine were carefully surveyed, and the dam sites were thoroughly contoured on a very large scale, and the survey brought to such a condition that estimates of the cost of construction can be made at any time, whenever a Board of Engineers can agree upon what is the most suitable form of dam to be constructed. There is a high-line canal, taking water from six to nine reservoirs, which constitute a system, and bringing the water out upon the bench lands above Sun River, where it can be utilized.

Senator MOODY. Do you take the water from all those reservoirs into one canal—one general canal—or do you run a canal from each one of these reservoirs?

Captain DUTTON. A high-line canal takes the water from all the reservoirs; so they are practically one system.

Senator MOODY. Is that the mode of expenditure of the balance of the money, generally speaking, in all the States and Territories you have mentioned?

Captain DUTTON. That is not the exclusive method of the engineering work. In the Arkansas Valley the work has been somewhat different. It has there been devoted partially to the same end, that is, to devising a unified scheme for the maximum development of the irrigation possibilities of that hydrographic basin.

Senator MOODY. That is, selecting sites?

Captain DUTTON. Selecting sites and estimating the cost of construction.

Senator MOODY. Carefully surveying the sites?

Captain DUTTON. Yes, sir.

Senator MOODY. Locating the sites of dams?

Captain DUTTON. Yes, sir.

Senator MOODY. What else?

Captain DUTTON. Preparing surveys which can be utilized at any time.

Senator MOODY. Which can be utilized for the distribution of the waters.

Captain DUTTON. Yes, sir.

Senator MOODY. Outside of that what special work has been done?

Captain DUTTON. In addition to that there has been the selection of a large number of possible reservoir sites, which up to the present time have not been co-ordinated with any particular system, but which may be co-ordinated at any future time. Furthermore, there has been a considerable amount of money expended in the segregation of irrigable lands.

Senator MOODY. What do you mean by the segregation of irrigable lands? Do you mean the ascertainment of the areas of the lands that are susceptible of irrigation?

Captain DUTTON. The law provides, as you will remember, that all of the lands which are rendered susceptible of irrigation by such hydraulic works as are mentioned in the law are withdrawn from occupation, sale, and entry. Of course it is necessary to specify what those lands are, giving the township, range, section, quarter section, etc. Now there are a great many lands about which we are uncertain, but there are still others, of very large extent, about which no uncertainty exists, and it was deemed best to take those instances where no uncertainty existed at all and have them reported to the Secretary of the Interior for withdrawal from entry, occupation, and settlement, and do it promptly.

Senator MOODY. You have ascertained, then, by your surveys, the areas of lands susceptible of irrigation and that can be brought under irrigation by means of this system of reservoirs and distributing works that you have been planning?

Captain DUTTON. Yes, sir.

Senator MOODY. And marking upon the ground?

Captain DUTTON. We took the Land Office surveys. They are marked on the ground, in most cases. We took the Land Office plats, and from draughts of the Land Office plats we made our own draughts and certified them to the Department.

Senator MOODY. Do you do that by survey or mere observation?

Captain DUTTON. By sending a competent party upon the ground to identify the corners.

Senator MOODY. Will you state generally, as briefly as you can, how the $120,000 which was assigned to the topographic service has been expended?

Captain DUTTON. I only know in a general way where the field-work has been?

Senator MOODY. I am only asking for the information you have gathered from your familiarity with the office work.

Captain DUTTON. I can only state that from my general knowledge of where the work has been carried on. There have been a number of field parties at work in the Sierra Navadas, along the boundary line between California and Nevada. There has been a field party at work in the Snake River Valley, in the vicinity of Idaho. There has been a very large field party, or series of parties, at work in the Arkansas Valley in Colorado. There has been another large party at work in the valley of the Yellowstone and on the upper forks of the Missouri,—and a year ago—I am not certain whether it is within the present year or not, but a year ago there was a party at work in the Rio Grande Valley, in New Mexico. I am not certain whether they have been continued during the present fiscal year or not.

Senator MOODY. What work do these parties do that is of value so far as the purposes of irrigation are concerned, except to furnish these information maps that you have spoken of, that you take and then go upon the ground to locate absolutely the reservoirs by actual surveys? What service have they performed in the direction of irrigation?

Captain DUTTON. Well, there are two stand-points from which that question can be answered.

Senator MOODY. I would like your views upon it.

Captain DUTTON. I think I had better answer it——

Senator MOODY (interposing). What I am trying to get at is this: I would like to know, if the committee has the patience to allow me——

The CHAIRMAN (interposing). Certainly.

Senator MOODY. I would like to know how much of this $250,000 has

been expended for the purpose of irrigation and how much has been expended for the purpose of mapping and platting the country. In that light I would ask you, captain, what work the topographic parties have done.

Captain DUTTON. I think the best answer I could give you would be to try to explain the matter from the stand-point of the Director himself.

The CHAIRMAN. Give the engineers' views and the Director's, both.

Senator JONES. It seems to me that you are likely to bring about confusion here. A topographic map may have great value in many different ways. It may or may not be necessary to have it for the purposes of irrigation. I do not believe you can have an intelligent method of irrigation without a topographic survey; but when a topographic survey is made it can be——

The CHAIRMAN (interposing). We want his view.

Senator MOODY. I understood the captain to say—and I may have misunderstood him—that the topographic surveys which were important for irrigation purposes were made by the engineering surveys.

Senator JONES. He said those that were indispensable.

Senator MOODY. They must have these vertical surveys.

Captain DUTTON. And on a very large scale.

Senator MOODY. On a very large scale; in other words that the mere togographer does not undertake to fix with any degree of accuracy the line of any canal or the altitude of any place, except for mere topographic purposes, and that after he is through with his work, or if he does not do the work, the engineering corps that is engaged in locating dams and reservoirs, and canals for the distribution must go upon the ground and make exact and accurate surveys. Of course every man understands that if you are going to run water from a reservoir you have to run some sort of levels, and run them with accuracy, and that a mere topographic survey will not do; but the topography you speak of, as I understand it, is that topography which comes from these accurate survey by engineers. Am I correct?

Captain DUTTON. That is correct; entirely so. To answer your question as you originally put it, I would say this: It was the Director's idea originally to have a topographic map constructed with a degree of accuracy which would be sufficient to enable engineers to dispense with costly and cumbersome parties of transitmen and levelers, and to produce maps which, taken in the hands of the engineer and carried into the field, would enable him to lay down his canal lines with as fair a degree of accuracy and certainty as if they were actually run by transit and level. That was his way of making an irrigation survey. I think that the Director was under a misapprehension as to the degree of accuracy in his maps which was attainable by the methods actually used by the topographers and under the requirements which were laid upon them. My belief is that no such degree of accuracy as would be necessary for the engineer was at all attainable by the methods adopted by the topographers, and I am quite confident that the topographers think the same way themselves, with the possible exception of Professor Thompson. That was the Director's desire in having a topographic map made.

The CHAIRMAN. Now, give the engineers' side of the question.

Captain DUTTON. The engineers' side of the question, I suppose, would be this: That a topographic map can not by any possibility be made with any such degree of accuracy as is required for the crudest and most general purposes of the engineer. In the next place, the

requirements of the engineer are for a very large scale map, a map merely of a strip of ground a few hundred feet wide along the path of his traverse; also for a very detailed map, on a scale never less than 200 feet to the inch, and most generally 100 feet to the inch, sometimes 50 feet to the inch for dam-site purposes. This minute survey on a very large scale is to enable the engineer to take the map into his office and estimate quantities, as we say. Similarly, also, the survey along the line of his traverse on a very large scale is necessary for precisely the same purpose as the railroad engineer makes it, in order to be able to estimate the quantity of excavations he has got to make and how to adjust his cuts and fills.

Senator MOODY. Pardon me for referring to another subject. What is the lowest grade of flow which you provide for in the canals or ditches to which you have referred?

Captain DUTTON. The lowest grade that I know of for a canal is about eight-tenths of a foot to the mile. The tendency among engineers is to adopt lower grades than they used to in high line canals, and if the country and economy of work will admit of it, they now prefer rather lower grades than they have ever used before.

Senator MOODY. How much is that to the rod?

Captain DUTTON. I should have to apply the arithmetic to it. It would be a very minute fraction of an inch.

Senator MOODY. Now, with that fall of grade what is the percentage of evaporation as the water passes through the canal; or let me ask, primarily, what is the degree of evaporation?

Captain DUTTON. There is no way of stating evaporation, Senator, except——

Senator JONES (interposing). In proportion to the surface.

Captain DUTTON. There is no way of stating evaporation except by ascertaining the amount of water evaporated in a given time, so many hundredths of an inch in a day, or so many inches in a month, or so many feet in a year. That is the only way in which we can state evaporation.

Senator MOODY. I have heard it asserted by hydraulic engineers that the average evaporation in a canal or ditch running slowly, as you have indicated would be the case, of course with a fall of eight-tenths of a foot to the mile, was about 3 per cent. a mile.

Senator JONES. Three per cent. of the volume of the water?

Senator MOODY. Yes, of the water in the canal or ditch.

Captain DUTTON. When I say that eight-tenths of a foot to the mile is the smallest grade that I know of I do not wish you to understand that is the grade for any great length of a canal. It is for only a certain portion or section of the canal, where certain reasons necessitate the use of a minimum grade. A minimum grade should not be resorted to in all cases. What the engineer wants is a grade which will enable him to get his water from the source of supply to where it is required in the shortest possible time. If he gets his grade too great, it will wash out his canal; if he gets it too low, it will increase the cost of construction.

Senator MOODY. The extent of evaporation depends largely upon the surface which is covered by a given amount of water?

Captain DUTTON. It is always in proportion to the surface, other things being equal. We consider that evaporation depends on three quantities: The first is the temperature of the water; the second is the absolute humidity of the air. There is still a third, the rate at which the wind is blowing, the wind factor being really the most important and the most difficult to handle.

The CHAIRMAN. I desire to ask one or two questions, and I want to call the attention of the committee to this matter. In constructing dams in northern Arizona, Nevada, New Mexico, parts of Utah, and parts of Idaho, where they have cloud-bursts in summer and violent storms sometimes in winter, that produce unusual floods, would any general topographic survey be of as much use to you as a particular examination of a given stream, with a view of ascertaining the evidences of what had happened there in the way of floods in the past? For example, if you have been through that country you have seen places where these cloud-bursts to which I have referred have occurred, carrying down immense rocks weighing hundreds of tons and gullying out deep ravines in the bald mountains, where the precipitation generally starts. Are there not evidences on the ground which would warn a person familiar with the country to build no dam under any circumstances in certain places, no matter what the topography might indicate? Are there not such places?

Captain DUTTON. Plenty of them.

The CHAIRMAN. Where any dam would be torn out. I have in mind a cañon in California—Panamint Cañon—which is very narrow and very steep. At the foot of that cañon there are immense rocks, some of them 50 or 60 feet high, which have been carried down through the cañons by the floods, by these cloud-bursts which prevail there, which occur frequently. To build a dam there would be folly. Now, when you deal with that country is it not more necessary than anything else to observe the evidences on the ground, ascertain the experience of those who have lived in the region, and if you are going to utilize that water take the water out of the stream and build your reservoir somewhere else? In dealing with a country like Arizona, is it not one of the first things to do to see what nature has already done and avoid those places where these cloud-bursts have occurred, and would a topographic map be of very much use to an engineer who is sent on the ground to find a safe place to locate his dam?

Captain DUTTON. It would not be of any special use.

The CHAIRMAN. It would be convenient to show the geography?

Captain DUTTON. Yes, sir; but when it comes to practical work, it would not be of any particular use.

The CHAIRMAN. What delay would be necessary in this work if we should wait for sufficiently accurate topographic surveys to precede the engineering work?

Captain DUTTON. A good many years, unless the topographic survey was conducted so as to meet the wants of the engineers at the very start.

The CHAIRMAN. Is there any topographic survey now in existence that is sufficiently accurate for use in locating a dam and line ditch without this same engineering work which you speak of?

Captain DUTTON. I think that probably some of the English ordnance survey maps might ——

The CHAIRMAN (interposing). I mean in this country that has been made by any of the surveys you have mentioned?

Captain DUTTON. I do not think there is.

The CHAIRMAN. You are familiar with what has been done. Take for example this district. Do you know of efforts having been made to secure an accurate topographic map of this?

Captain DUTTON. I know the Coast Survey made some good maps during the war, and I think the city engineer has run some careful surveys.

The CHAIRMAN. Has not the Coast Survey been at work for the last few years in trying to make an accurate map?

Captain DUTTON. Possibly they have.

The CHAIRMAN. You have not seen that map?

Captain DUTTON. No, sir.

The CHAIRMAN. Do you know whether that map of the District of Columbia, on which they have spent so much money, is sufficiently accurate for locating a line of railroad, or a ditch, or a dam? Could you do those things by that map without engineering work? I suppose that is the best map we have in the United States.

Captain DUTTON. I would have to study the map before I could form an opinion.

The CHAIRMAN. You have not studied the map?

Captain DUTTON. No, sir.

The CHAIRMAN. Then we need not, in your judgment, wait for the topographic survey to prosecute what surveys are necessary for immediate use.

Captain DUTTON. I do not think it is necessary.

Senator REAGAN. Captain, has the hydrographic and engineering work covered the whole ground of the topographic work? If it has not, what proportion of the topographic work has been covered by the hydrographic and engineering work?

Captain DUTTON. While the topographic and engineering work are in most cases in the same neighborhoods, the only case of actual coincidence is in the Arkansas Valley. The topographic work was commenced there about a year and a half ago, I think, and the engineering work only last summer. In all other portions of the West the two fields of labor have not coincided.

Senator REAGAN. If you should take a topographic map, according to the way the work is now being done, could you not lay down a common road or railroad by it?

Captain DUTTON. You could point out in a general way, perhaps, where a common road might be laid out. I think, however, there are some portions of a topographic map where that would be very doubtful. As to a railroad, I should say no. It would not dispense with the necessity of a railroad survey.

Senator REAGAN. You could get the general line of a railroad from it?

Captain DUTTON. Well, in a general way you could. I think so.

Senator REAGAN. Can you take a topographic map and select any particular stream and determine the catch basin of that stream by it and the amount of land that would be irrigable?

Captain DUTTON. No, sir; you would have to go over the ground to ascertain the amount of irrigable land.

Senator REAGAN. Where it is above 4 feet altitude you could get the place where your reservoir would have to be located, you could get the size of your catch basin, and you could determine what lands are lower than your dam?

Captain DUTTON. They only make the maps with 20-foot contour.

Senator REAGAN. Then I have been wrongly informed at the Department, for I was told there that they had made the maps on a 4-foot contour.

Captain DUTTON. Possibly it may be that in the Mississippi Valley.

Senator REAGAN. No, I am talking about the Western country.

Captain DUTTON. It is a 20-foot contour, unless they have changed without my knowledge very recently. I know a few months ago it was understood to be 20-foot contours in the valleys, 50-foot in the foot-hills, and 100-foot in the mountains.

Senator JONES. You say a topographic map is of very little value to the engineer in locating irrigating works.

Captain DUTTON. I think they are of only general value.

Senator JONES. And are by no means necessary.

Captain DUTTON. I do not think they are necessary within the meaning of the law, and yet there is this to be said about it: The term "necessity" has a practical interpretation; is not easy to define. We are every day certifying that certain things are necessary on our bills and on our vouchers. While in a certain sense and in the ordinary acceptation of the term they are necessary, in an absolute sense they are not.

Senator REAGAN. What is the use of a topographic survey?

Captain DUTTON. To furnish general information about the country and a knowledge of the laws of distribution.

Senator REAGAN. Has the Government made a mistake in authorizing these topographic surveys?

Captain DUTTON. No, sir; I think not. I think no money has been better spent.

Adjourned.

DEPARTMENT OF THE INTERIOR, U. S. GEOLOGICAL SURVEY,
Washington, D. C., March 31, 1890.

DEAR SIR: I have the honor to acknowledge the receipt of your letter of 29th instant, desiring me to inform you concerning the expenditures made in the Geological Survey under the appropriations made in 1888 and 1889 for irrigation surveys, viz:

First. Of the exact amount of the two appropriations of 1888 and 1889, the first for $100,000 and the second for $250,000, which was assigned to topographical work and to engineering surveys for irrigation purposes, and how much has been used in the office for topographical work and how much for the work of irrigation.

Of the first appropriation for $100,000, the sum of $40,000 was at first allotted for engineering and hydrographic work, but at a later period $4,000 of this sum was transferred to the allotment for topographic work, making the allotment for engineering and hydrographic work $36,000 for the fiscal year ending June 30, 1889. A sum of $4.000 was understood to be reserved by the director for office expenditures. The amount finally allotted for topographic work I understand to have been $60,000. As regards the last two items, however, my statement is not necessarily conclusive, since I have had no formal or official notification thereof. As to how much has been used in the office for topographical work and how much for irrigation work, I can not give a complete answer except by stating the general nature of the case.

There are numerous expenditures, such as heating, lighting, watchmen, messengers and clerks in the Director's office, purchase of stationery, printing, express charges, carpenter work, repairs, etc., which are for the common benefit of all branches of work under the Director's administration, and it would be impracticable to charge these expenses to the several allotments except in an arbitrary way. They become, therefore a charge against the reserve funds which are divided off from each appropriation. Moreover, it is usually the case that expenses slightly overrun the the allotments, and the excess is paid from the reserve fund at the end of the fiscal year. The work under my charge overran the $36,000 allotted by the amount of $743.33. How much the topographic work overran its allotment I do not know.

During the present fiscal year the sum of $110,000 ha sbeen allotted for the engineering and hydrographic work. My understanding is (though I have not been informed officially to that effect) that $120,000 has been allotted to topography and $20,000 held as a reserve fund. To what extent the allotments will have to draw on the reserve fund at the close of the year can not, of course, be exactly foreseen at present. Up to this date there are charges for work under my control amounting to $3,667.44 which were not estimated for at the beginning of the fiscal year and which will become a proper claim against the reserve fund. I do not now see any reason to expect that this amount will be materially increased. Of the state of the topographic allotment I have no information.

If I rightly apprehend the purport of your first inquiry, your desire is to know what disposition has been made or is intended to be made of the three portions (engineering, topography and reserve) into which the appropriation has been divided by the discretionary action of the director. With that understanding, the nearest approach which I can make to the exact information you seek is as follows:

From the first appropriation of $100,000, $36,743.33 have been explicitly expended for the engineering and hydrographic work. For the topographic work, I understand that $60,000 have been allotted and presumably expended. Of the remaining $3,492.23 I have no knowledge beyond the fact that there have been numerous sources of necessary incidental expenditure to which it may have been applied for the common benefit of both the engineering and topographic work without being distinctly chargeable to either one alone. A portion of it might also have been available at the end of the fiscal year to meet expenses in excess of the allotment for topography.

Second. You further inquire how much of the entire expenditure was for topographic work during the last fiscal year in the region west of the one hundredth meridian and whether the topographical work of the arid region since the appropriations for irrigation has been carried on with money for topography or with money appropriated for irrigation.

I have not the full information and knowledge which are necessary to give an exact answer to this question or to furnish the figures. But in general terms, I understand that on July 1, 1888, topographic parties were at work in the arid region under the appropriation for topography only, and continued to work so during the remainder of the summer. The first appropriation for irrigation became a law on October 2, 1888, and within a very few weeks parties were put to topographic work in the Arkansas basin at the expense of the irrigation appropriation, and in the spring other parties took the field in California, New Mexico, and Montana under the same appropriation. During the current fiscal year my understanding is that all of the topographic work of the arid region has been at the expense of the irrigation appropriation and that no portion of the topographic appropriation has been expended there.

Third. In what section was the first $100,000 appropriated for irrigation expended in engineering work for irrigation and what amount of irrigation survey was completed with the first appropriation and what area of land was covered? Where has such portion of the second appropriation as was assigned to irrigation been expended, and what was accomplished in each district?

Immediately after the passage of the appropriation October 2, 1888, measures were taken for organizing the hydrographic work. As the funds could not become available until the 1st of November, when the winter would be upon us, it was deemed unwise to immediately organize the engineering work. For the hydrographic work skilled men of high intelligence were necessary, and there were probably not two dozen men in the United States who knew how to gauge a stream, and not one of the few who did know were available. It is an art requiring manual skill, the intelligence of an educated hydraulic engineer, and the temperament of a somewhat scientific observer and manipulator. Neither was there any well-established and generally-accepted method of stream gauging, nor any standard instruments. In short, there was no regular practice. It was necessary, therefore, to create men, methods, and instruments. It was believed that good gauging would be impracticable in wintertime, and of little value even if it were practicable, and hence that no better course could be followed than to select promising, well-educated, and ambitious young men, put them into a camp of instruction in a moderately warm climate during the four or five months of winter, and let them acquire the necessary skill, work out methods of gauging, and ascertain by trial the best kinds of instruments to be used. This was done. A good comfortable camp was established on the Rio Grande in New Mexico, and fourteen young men sent there early in December. They applied themselves with great zeal and interest, and with two or three exceptions proved to be most excellent men. When the spring approached I had about a dozen men at my command who knew what was wanted of them and how to do it. Up to the 1st of April the expense of the work for all purposes was $10,400. The men were then distributed to their stations; two in New Mexico, two in the Arkansas Valley, one in California, one in Nevada, two in Utah, one each in Arizona, Idaho, and Montana, and one at El Paso, Tex. Gauging stations were established in the following basins:

Rio Grande and tributaries, 6 stations; Gila and Salt Rivers, 3; Carson and Truckee 7; rivers of Utah, 14; Snake River basin, 5; Upper Missouri and Yellowstone, 12; Arkansas basin, 6.

Evaporation stations were also established at El Paso, Phœnix, Yuma, Clear Lake, California; at several localities in Utah, two in Idaho, five in Montana, and two in Colorado. About seventy special stations were established at high altitudes in Arizona, New Mexico, and Colorado for observing rain and snow fall at places not reached by the Signal Service. Many hundreds of gaugings were performed and a large amount of special inquiry made into the duty of water. At the close of the fiscal year the work was progressing in a highly satisfactory manner except in the Carson and Truckee basins, and though the work here was not what was expected it has proved to be less faulty than was at one time feared. Everywhere else it has been better than was anticipated for the first season.

The engineering work was not organized until spring, first, because winter work is undesirable unless an emergency demands it, and, second, because the allotment at

my disposal was insufficient to accomplish any work of much value. In May two supervising engineers, Messrs. Hall and Nettleton, were appointed, and four division engineers, Messrs. Foote, Bodfish, Bridges, and Wilson. The funds remaining available would not admit of more than buying the outfits and putting the parties in the field in time to accomplish three or four weeks' work, *i. e.*, just make a beginning of their work, by the time the fiscal year closed. The parties were launched in the Arkansas basin under Mr. Bodfish about June 1; in the Snake River basin under Mr. Foote about the middle of May; in Montana under Mr. Wilson about June 1; and in the Truckee basin under Mr. Bridges about the middle of June. At the close of the fiscal year it may be said that something had been begun by the engineers but nothing had been completed.

The only segregation work was the withdrawal of Utah Lake and Bear Lake as reservoir sites, which were carefully surveyed for that purpose by two of the hydrographers.

The total cost of the engineering work, including all expenses, direct and indirect, up to June 30, 1889, was $7,550.19, of which the greater portion was for the outfitting of the parties The total cost of the hydrographic work and the expenses of my own office, including also the purchase of a large number of new instruments of a costly kind, was $29,193.14.

Under the second appropriation the following work has been done:

There have been practically seven divisions of engineering surveys, one of which was not anticipated at the beginning of the year, viz, Utah, but was opened in consequence of special orders of the Secretary of the Interior.

First. Montana. Mr. Wilson began his work by an energetic reconnoissance of the valleys of the Yellowstone, the Gallatin, the Madison, and the Jefferson, the Missouri between Bozeman and Great Falls, the Sun River, and the upper portion of the Musselshell. He went alone on horseback, with only a hand-level in his pocket, and in the course of a little more than three months reported sixty-three large reservoir sites for withdrawal, and about 11,000,000 acres of land for segregation. The reservoir withdrawals were well done and satisfactory in every way. Question arose in my mind concerning the segregation of so vast an area (about 17,500 square miles), but a careful examination of his report, in conjunction with a knowledge of the country, satisfied me that the doubtful questions were whether he had not omitted land which he should have included, rather than included land which he should have omitted.

Mr. Wilson soon reached the conclusion that some of the best lands in Montana might be watered by a system of reservoirs and canal, taking the flow of the Sun River. He immediately began a survey there. In the course of the season his assistant, Mr. J. B. Rogers, ran a preliminary line of a canal 80 miles long, surveyed ten large reservoirs on a scale of 500 feet to the inch, and dam sites and waste-weirs 100 feet to the inch, with 2 foot contours, all in sufficient detail to enable close estimates of cost to be made. It is a fine piece of survey work, and shows admirably how much can be done by intelligent projects and how great are the possibilities of a sound comprehensive, systematic development. The cost of the entire engineering surveys in the Montana division up to March 1, including expenses in field and office, is $6,574.71.

In the Arkansas division, Mr. Bodfish, under the immediate eye of Mr. Nettleton, was instructed to investigate the possibilities of increasing the useful water supply of that river by storage, and of utilizing its return waters upon the plains near the Kansas line. He has surveyed in great detail ten large reservoir sites in the vicinity of Leadville and Buena Vista, also one on Monument Creek, near the base of the front range. He has examined all the tributaries on the north or left bank of the river for reservoir sites, reporting twenty-five of them for withdrawal. The southern tributaries would have been examined had not the premature coming of winter buried the country deep in snow. He has, I believe, exhausted the reservoir sites so far as he has gone. He has also run a canal line, starting from near Granada, above Garden City, a distance of 146 miles, to test the question of using the return waters in the river upon lands of western Kansas. The project of utilizing Twin Lakes for a reservoir is a most promising one and the survey work has been done in a highly satisfactory manner. The total expenditure in this division up to March 1 is $9,466.13.

In the Rio Grande division the engineering work was not started until July. Mr. W. W. Follett was appointed division engineer. He at once began the survey of a project for a dam and reservoir at El Paso, and completed his survey about the last of August. It included a contour and cross-section survey of the great reservoir basin, with close estimates of capacity; sounding the quicksands in the bed of the river to ascertain the surface of the bed rock in two sections of the river; a close survey of the two dam sites, and a relocation survey of the Southern Pacific and Atchison, Topeka and Santa Fé railroads. His report of a project, with estimates of quantities and of cost, has been submitted.

During the winter Mr. Follett has been engaged in the segregation of irrigable lands in the Rio Grande Valley in New Mexico. He was instructed to proceed to the office

of the Surveyor-General in Santa Fé and prepare a compilation of the Land Office plats of that valley, and to then make a close detailed segregation, denoting all land grants, railroad grants and all claimed lands, section by section, and to verify the segregations upon the ground. Also, to select all possible reservoir sites and report them for withdrawal, and all natural dam sites, whether on the main river or its tributaries. He was to begin his work at Fort Seldon and work northward to the Colorado boundary, cleaning up as he went. He has sent weekly reports of his itineracy and lists of specifications of selected lands, and is now within about 60 miles of the Colorado line. He has reported about sixty reservoir sites. The amount of land reported I have not computed, but it will be some millions of acres. This careful segregation was deemed necessary here by reason of the tangle of land grants and other claims in various stages of adjudication. The cost of the El Paso Reservoir surveys was $2,210.59. The cost of the segregation work up to March 1 was $1,744.10.

In California a survey was made of Clear Lake to ascertain its possibilities as a storage reservoir. This was an extensive survey and the work was of a high order and in the most thorough detail; in fact, I think it will rarely happen that so extensive a survey will be called for.

A well-equipped party was also sent into the mountains around the headwaters of the Stanislaus, Tuolumne, and Merced Rivers to search for reservoir sites. Eight good sites were found and were surveyed. Some doubtful ones were also discovered and marked down for further examination.

A reconnoitering party of two men was sent into Lassen and Modoc Counties, east of the Sierras, to search for reservoir sites, and found two very large ones with a considerable water supply. This party expended a large amount of money and accomplished but little.

A fourth party was sent to Owen's Valley to segregate irrigable lands and examine the headwaters of the river for reservoir sites. They were instructed to make a close segregation in the same manner as Mr. Follett was in New Mexico. They completed the segregation work in the lower valley for a distance of about 100 miles along the river front and were about to proceed to the upper valley when the early severe storms set in and put an end to the work. Their results have been reported in a satisfactory manner as far as they went. The total cost of the work in California was $11,483.47 to March 1.

In the Truckee and Carson basins Mr. Bridges made detailed surveys of Donner, Independence, and Webber Lakes as reservoir sites. A survey was made for a reservoir in Long Valley, with canals taking water across the Carson River to the lands on the east side of the Carson Valley. This last survey was not approved, nor was it authorized or intended. A survey was also made of Hope Valley at the headwaters of the west fork of the Carson. A trial line was surveyed from a point about 5 miles above Wadsworth to the lands southeast of that town to ascertain the possibilities of carrying water to them from the Truckee River. A large amount of canal line was surveyed by Mr. Bridges, but as none of the others was authorized or approved no further mention is made of them. His management of his division being very unsatisfactory he was relieved from duty by me, and at my request was asked by the director to resign. The surveys of Donner, Independence, and Webber Lakes and of Hope Valley are of some value, but not commensurate with the expenditure. The accounts of the engineering work in this division were closed on the 30th of September, and at that time the expenditures were $13,495.36. Since that time further office expenses were incurred in the office of the supervising engineer, Mr. Hall, which bring the total amount to about $15,500. The exact figures it would require considerable labor to extract from the itemized vouchers. They appear on my books with the expenses of the office of the supervising engineer.

In Utah it was originally intended to do nothing but hydrographic work, but circumstances forced other work upon us. Mr. Newell, as hydrographer, was found to be an object of great interest to the people of the Territory, who sought his official action with great eagerness. He was soon required by me to make a survey of Utah Lake, which was done in the preceding year. It soon became manifest that numerous other reservoir sites ought to be examined, and this was done and the sites were withdrawn but not surveyed. Later, an order was received from the Secretary of the Interior to segregate the irrigable lands in Bear River Valley. Instructions were therefore given Mr. Newell to make a close segregation, section by section, and to verify his work on the ground, and also to add to it some traverse and level work to clear up doubtful questions in some localities where disputes or complications by reason of existing claims and filings might arise. The work was speedily accomplished. Over 2,000,000 acres were reported for segregation, and a plat of the work, based on the Land Office plats, was furnished and duly certified. The cost of the segregation work was $1,579.56.

In Idaho Mr. Foote was instructed to survey thoroughly a project for a pair of grand canals, taking water from the Snake River at Eagle Rock, one branch running south to Pocatello, the other running west into the desert. This was to be only a single feature of a comprehensive system of canals and reservoirs for utilizing as

much of the water of the river as could be stored in addition to its natural flow. An excellent dam site with an ample waste weir was found at Eagle Rock, and a location survey was begun at once without any preliminaries on the left bank, and carried 70 miles to Pocatello, where the line was tailed into the Portneuf.

The line was carried on to the westward nearly to American Falls, where it was found to be impracticable to carry it further. A new line was started at American Falls, and carried only 14 miles, as it was found to be impracticable. Another line was surveyed from the Snake near Minedoka, but was not completed, owing to stormy weather. It was found to be practicable.

Mr. Foote also made a reconnaissance up the forks of the Snake River in search of storage capacity. An indefinite amount of it was found at Jackson Lake, but present appearances indicate that the whole annual flow of the fork issuing from Jackson's Lake would probably be not much more than 500,000 acre-feet, while the capacity of the basin is probably four or five times that amount. The dam site is excellent.

Another grand reservoir site was found in Swan Valley, much lower down, on the South Fork. Here the flow of the river is very much greater. The capacity of this site is more than a million, and may be nearly a million and a half acre-feet, with plenty of water to fill it. A good dam site with an abundant waste weir exists. Another immense site was found on the Falls River Branch of the Snake where probably 300,000 or 400,000 acre-feet could be very cheaply stored. Several other large sites were found, but not sufficiently examined to enable statements to be made with confidence concerning them.

Mr. Foote was further instructed to report all irrigable land in the valley of the Snake above American Falls for segregation, and he has reported over 10,000,000 acres.

During the past month he has begun a location survey of the other canal, taking water at Eagle Rock on the other side of the Snake, and his parties at last accounts were in the field. Before the close of the present fiscal year it is expected that more than 100 miles additional of canal line will be surveyed. These location surveys of Mr. Foote are done in a very thorough manner, and his drawings are cross-sectioned and afford the means of making estimates of cost. His plats have been received and are apparently excellent work. The total cost of the engineering work of this division up to March 1, has been $9,590.19.

It remains to add the expenses of my own office and those of the supervising engineers, of which separate accounts are kept. The salaries of the supervising engineers are included in them, my own salary being paid from the appropriation for the Army: Chief Engineer's office $7,119.39; Mr. Nettleton's office, $4,966.87; Mr. Hall's office, $7,151.50.

My own office includes a disbursing agent, who does all the disbursing under my charge; a single type-writer; two draughtsmen, who prepare all the segregation work for the General Land Office, have charge of the engineering maps and drawings, their proper recording and filing, also of the hydrographic records and reductions and miscellaneous draughting work.

As regards the hydrographic work during the fiscal year I may speak more briefly. Many of the chief rivers of the west have been put under thorough observation by ganging and by continuous records of rise and fall. They are the Arkansas, the Rio Grande, the Gila and Salt, the Carson and Truckee, all the rivers which flow into Salt Lake and Utah Lake, the Sevier River in Utah, the Snake with its forks, the Wood River and Lost River in southern Idaho, the Weiser, Payette and Owyhee, the Missouri, the Yellowstone, the Gallatin, Madison and Jefferson, and the Sun River. Many of these have observing stations at several points and on their minor tributaries not specified. We now have continuous records worked out, computed and exhibited in diagrams, showing their daily discharges for the whole summer and until the rivers were closed by ice. In the southern territories the records are continuous throughout the winter. The hydrographic work has, on the whole, gone on with better success than was expected at the start, and much credit is due to the young men who have accomplished it. The work, however, gives plain indications of being somewhat starved by reason of excessive but unavoidable economy. But another year will, if permitted to continue, show a very great advance. The total cost of the hydrographic work from July 1, 1889, to March 1, 1890, has been $19,984.72.

The following is a summary of the work done and the cost:

Reservoirs fully surveyed to estimates.

Montana	10
Colorado	10
El Paso	1
California division	9
Truckee and Carson	5
Total	35
Reservoirs reported for withdrawal	144

Canal lines fully surveyed to estimates.

	Miles.
Snake River Basin	157
Arkansas River Basin	146
Total	303

Canal lines roughly surveyed.

	Miles.
Montana, Sun River	80
Truckee Basin	22
Total	102

NOTE.—About 160 miles of canal line were surveyed in the Truckee and Carson Basins, but only 22 miles are accepted by this office.

Number of acres of land reported for segregation, about 30,000,000.

Cost of work.

	First appropriation.	Second appropriation.	Total.
Hydrographic	$29,193.14	$19,984.72	$49,177.86
Engineering work:			
Montana division	1,080.11	5,494.60	6,574.71
Arkansas division	1,308.94	8,157.19	9,466.13
Rio Grande division	.....	3,954.69	3,954.69
California division	605.01	10,878.46	11,483.47
Truckee and Carson	2,314.01	11,181.35	13,495.36
Utah	.....	1,579.56	1,579.56
Snake River	2,242.12	7,348.07	9,590 19
Supervising engineers	.....	12,118.37	12,118.37
Total engineering	7,550.19	60,712.29	68,262.48
Chief Engineer's office	.....	7,119.39	7,119.39
Aggregate	36,743.33	87,816.40	124,559.73

Very respectfully, sir,

C. E. DUTTON.

Hon. WILLIAM M. STEWART,
United States Senate.

SIXTH DAY'S SESSION.

WASHINGTON, D. C., *March* 14, 1890.

The committee met pursuant to adjournment.

Present, the chairman, and Senators Reagan, Jones, Moody, and Casey.

FURTHER STATEMENT OF DIRECTOR POWELL.

The CHAIRMAN. Major Powell, the point that the committee desires your views upon this morning is as to the necessity of topographic surveys preceding the engineering surveys for irrigation, the relation of the two classes of surveys, and whether the engineering surveys can be carried on independently of the other, or whether they are necessarily connected.

Director POWELL. Mr. Chairman, there are two branches of the subject which I wish to present: First, the plans and methods of the survey, as necessary to carry out the provisions of the statute; and second, I

wish to call attention to and review the statutes and the reports which I have made to Congress on calls from the Senate which represent the needs of an irrigation survey, for the purpose of showing that the wording of the statute and the representations made by me to the Congress prior to the passage of the statute are in harmony with what has actually been done. That is, I wish to show, first, what the irrigation survey should be, what is necessary to be done, and the information required; and second, to show that before the passage of the law I had fully set forth the facts to Congress, and that the wording of the statute calls for the work which has actually been done.

The CHAIRMAN. We are not complaining of what has been done. We simply want to know how these surveys are dependent upon each other.

Director POWELL. These two lines I would like to be heard upon. First, then, I wish to address myself to the question, what is necessary to be done in an irrigation survey, and how can this be done in the most economic manner? The statute provides, first, that the extent to which the lands can be redeemed by irrigation shall be determined; second, that reservoir sites shall be selected; third, that canal sites and sites of other hydraulic works, such as diverting dams, etc., shall be selected; fourth, that the lands made irrigable by these hydraulic works shall be selected; and, finally, that all of these sites and lands shall be segregated—that they shall be selected on the ground, as I understand it, and be certified to the Land Office, in land-office terms of township, range, section, etc., for the purpose contemplated in the law. In order to accomplish the end a survey had to be prosecuted and a series of discoveries made. These discoveries may be divided into three classes: Those relating to the land—the catchment areas, the sites for diverting dams and canals, the sites for reservoirs, and the irrigable lands. These necessities give rise to the topographic branch of the Irrigation Survey. Second, those relating to the water; that is, it is necessary to determine the amount of water which can be used for irrigation in each hydrographic basin or area drained by one important stream and its tributaries. It is necessary to determine the mean amount of water for the irrigating season in each basin, and also the mean amount of water for the entire year, and it is also necessary to determine the minimum amount in seasons of excessive drought and the maximum amount in seasons of excessive rain-fall. It is also necessary to determine the amount of water required to irrigate an acre of land, that is, to determine the "duty" of water. The necessity for determining all of these facts in relation to water gives rise to the second branch of the Irrigation Survey, that is, the hydraulic branch. Third, those relating to estimates of the cost of dams, canals, and reservoirs. For this purpose the sites of the dams must be surveyed with accuracy and the constructive conditions as to the proximity and character of materials must be studied. The sites of the reservoirs discovered by the topographic survey must be carefully examined and plans for their construction made. The sites of canals, the general routes of which are previously discovered by the topographic survey, must be carefully run upon the ground and marked, and the amount of cutting and filling determined, and the ground minutely examined for the purpose of discovering its character, whether it be in sand, clay, gravel, or solid rock, as all of these facts affect the cost of the work. Having studied these facts the cost of construction can be properly estimated. These three classes of work all relate directly to the Irrigation Survey. They are all required by the provision of the statute, and no one can be neg-

lected without disobedience to law. The three kinds of work give rise to three branches in its organization, which we call the topographic, hydrographic, and engineering branches.

The topographic survey is the work primarily necessary to the discovery of sites, though it has another use in the hydrograpic survey, as will be shown when that point is reached. In investigating this subject for the purpose of determining the best and most economic method of discovering the various sites required, it was decided that a topographic survey was proper. If a specific reservoir site is already known, and the body of land to be served by the waters from that reservoir is already known, the simple problem is to find a way for a canal from the reservoir to the land. Such a survey would need only the work necessary to run a number of trial lines on the ground and then to select the best from these. But the problem before the survey was not to irrigate some one man's farm from some one stream or reservoir site; it was not to irrigate some particular piece of land to suit some particular person; but the problem was to discover all of the reservoir sites, all of the canal sites, and all of the lands that could be irrigated in any given hydrograpic basin. How this could be done in the cheapest manner was the question which I had to solve. Having a specific reservoir in sight and a specific body of lands in view, and wishing to take the water from that reservoir to that piece of land, I can run trial lines and find the best route at the rate of about $25 per mile for each of the trial lines; but the final line selected must be run again with great care; the whole ground must be studied, very exact levels must be run, and all the characteristics of the line must be determined, in order that the cost of the canal may be discovered. But in the work of the irrigation survey the reservoir sites, the canal lines, and the lands to be irrigated have all to be discovered—ten, twenty, fifty reservoirs perhaps in one hydrographic basin; scores of canal lines, 10, 20, 50, 100 miles in length. To run many such trial lines over the ground for the purpose of selecting a few would involve great cost. The system of discovering canal lines by a topographic survey instead of by a trial line survey is very much less expensive. Certainly it would not cost more than one-third of the amount. To discontinue the topographic survey and inaugurate a trial-line system would be to increase the cost of the work fully three times. In the same manner the reservoir sites are to be discovered, and their relation to the streams which furnish them water and to the lands which they are to irrigate must be determined. Some of these reservoir sites are in the mountains—the best are there; some are in the valleys and on the plains. They are therefore widely scattered throughout all parts of each hydrographic basin. To discover them by trial lines instead of topographic surveys with contours would be to increase the cost of the work at least three times.

A hydrographic basin may furnish only a half a dozen good reservoir sites, or it may furnish two or three hundred, as the case may be. Some will be small, sufficient for reservoirs to hold 1,000 acre-feet of water; others will be great, sufficient for reservoirs to hold 1,000,000 acre-feet, or even 2,000,000 acre-feet of water. One reservoir site may be excessively expensive, another very economic; that is, it may cost $10 per acre-foot of water to store it, or it may cost but 10 cents per acre-foot of water to store it. It becomes necessary, therefore, for economy's sake, to select the best sites. In order to do this it is necessary to discover all of the reservoir sites of each hydrographic basin. If I were to select a score of reservoir sites in a basin at random and have these reserved to be used by the people in the future, and it should be found

that half, or many, or all of them were not as good as other sites in the same basin, and that a system of reservoirs could be constructed to store the water for one-half or one fourth of the cost that would be required in the basins carelessly selected, the whole work would be repudiated by the people; it would be misleading and injurious. It is therefore necessary for me to know in each basin all of the reservoir sites in the basin, that the best may be selected. This means that I must know every valley in the basin.

To illustrate the method of discovering these reservoir sites, I have brought with me the maps constructed by the topographic survey in the upper basin of the Arkansas in Colorado. These are the maps constructed in the field. On examination you will see that they are in contour lines; that the vertical interval from one contour to another in the valley region is 25 feet, in the hill regions 50 feet, and in the mountain regions 100 feet. It is not necessary to do the work in the mountains with the same degree of refinement as in the valleys. For more than twenty years I have been engaged in making topographic surveys in connection with the other work under my charge. During that time I have employed a corps of men of ability and genius, and during that time I have topographically surveyed about a half million square miles of country, on various scales and with varied degrees of refinement. Through the inventive genius of the men who have been employed on this work new methods of survey and new instruments have been devised, so that the whole system of topographic surveying has been revolutionized, and to correspond with it the method of map construction has been greatly developed and improved. The work has been improved in quality and enormously decreased in cost; and gradually other nations of the world are adopting our system.

The topographic survey which we are making in connection with the irrigation survey is in most particulars the same that we are making for the geological survey. The topographic work necessary for the one is necessary for the other, and we were making these maps for the Geological Survey before the Irrigation Survey was inaugurated. The cost of the irrigation survey, therefore, was only the cost of what was additional to the work already in progress. The work of the irrigation survey is, for the reasons I have stated, in the first place a topographic survey, because the sites for the works and lands are to be discovered, and it is the cheapest and best way of discovering them. In the maps before you you will see that the topographers have discovered forty-three reservoir sites and marked them upon the maps. They are colored in blue. The contour lines are colored in light red, as you see, and the reservoir sites are determined by the contour lines. Each site represents a valley basin, and in general terms, the height of the dam, the size of the basin, and its capacity are revealed by the maps which the topographers have constructed. From these about twelve or fourteen have been selected by the engineers as being, all things considered, the most eligible. The twelve or fourteen must be surveyed with greater care for the purposes already indicated, that is, to determine the cost of construction and to mark them upon the ground. That is the work of the engineering branch of the survey. In the same manner these maps reveal the general lines of the canals. They show, for example [indicating on the map], that the water from this reservoir can be taken along this line to this body of land. The map reveals other lines by which it can be taken and shows that this one is the best, and the engineers have selected it and have actually run it upon the ground and obtained the facts necessary to estimate its cost.

When called upon by a resolution of the Senate for a plan for these surveys, and by the appropriations committee for an estimate of cost, I selected and recommended this method of prosecuting the work, because I believed it would be the most economic; and I estimated the cost of the topographic work, in addition to what had already been done in the country, to be about $4,000,000. In making this estimate I took into view the fact that already work had been done under the general appropriation for the Geological Survey, and that that work would not have to be done again. I further estimated that to determine the amount of water in each hydrographic basin that could be used for irrigation and the amount of land which could be irrigated thereby would cost an additional sum of $1,500,000; and finally, when it was decided by the committee that the sites should be surveyed for the purpose of estimating costs and of segregating the lands and reporting them to the Land Office as reserved under the provisions of the act, another $1,500,000 would be necessary, making in all for the irrigation of the arid lands the sum of $7,000,000. But this estimate was based upon the consideration that the work should be done in the manner which I have pointed out. If this cheap and comparatively accurate topographic method developed in the survey had not been known, and had the old methods of topographic surveying been in vogue, I should then have had to decide whether it was cheaper to make the discoveries of sites by the old method of topography or by the system of running trial lines; but having developed a more economic topographic method, it was only necessary to decide between this new method and the trial-line system; and the new method is by far the cheaper and in every way the more satisfactory; for, having done it, the entire work can be published and submitted to the people—not as the opinion of men engaged in the work, but as facts determined by instrumental survey—and presented by simple contour lines on maps, so that they can see for themselves all the facts and conditions.

Senator JONES. What is the scale of those maps?

Director POWELL. One inch to 1 mile. That is the field scale. We do not publish on that scale. It is reduced to 2 miles to 1 inch for publication.

The CHAIRMAN. Right in this connection let me make an inquiry. You have got these drainage basins mapped. Now, suppose an engineer should go into one of these drainage basins with such maps as you have, would it not be necessary, in order to do accurate work, to follow up the stream and work carefully over this ground again, to determine where to locate his reservoir and canals?

Director POWELL. No, sir. I will come to that.

The CHAIRMAN. Then could not an engineer, with the boundaries of the drainage basin indicated, go into the drainage basin and make accurate surveys and locations; or even if they were not indicated, could he not determine the boundaries of the drainage basin and do the mere engineering work with a view of practical work?

Director POWELL. No, sir; the engineer——

Senator JONES (interposing). This dotted line on the outside indicates the water-shed. [Pointing to map.]

Director POWELL. The dotted line is the catchment area. That shows what will feed this reservoir. [Indicating on map.] I will come to that in the latter part of my statement. I want to answer the chairman. An engineer who should go in there without the topographic map would have to select the site. If he went in to select the site, he would have to select it by running trial lines, and to run trial

lines would cost three times this. Now, when he comes to this reservoir, the engineer surveys it, but not all this catchment area. Instead of surveying the area outlined here, he surveys this area, the dam site itself, only, and surveys it in a minute manner. The topographic survey has found the reservoir site and the catchment area. The engineer has all the facts. Now, the engineer who goes in there runs a more careful line to find the amount of water that reservoir will hold, and the length and height of dam necessary, and that is all he has to do.

Senator JONES. In order to make an accurate reservoir is it not necessary to run those minute lines?

Director POWELL. Certainly.

Senator JONES. Before the people can go in and occupy the lands these lines have to be run?

Director POWELL. Yes, sir; those in that little basin; but we have saved him all that work [indicating on map], and have done it in the cheapest possible way.

Senator JONES. This work of setting apart and getting the areas is pretty much done all over the country, is it not?

Director POWELL. No, sir; nowhere in the United States except where I have made surveys.

Senator JONES. Have you not had the engineering work in certain cases precede your topographic surveys?

Director POWELL. Yes, sir, I have, and that I wish to refer to. On the passage of the act the people of the Western region were exceedingly anxious to have results. In the general study of this subject for the twenty years in which I have been engaged, and during which Mr. Gilbert, my first assistant, has been engaged, I knew of very many sites; they did not have to be selected. I knew that Providence Lake was a site; I knew that Utah Lake was a site; I knew that Hope Valley was a site; I knew that a number of other localities were sites; but I did not know all, only a small number. I set the engineers at work on places which I already knew, in order that I might meet a local want at the very earliest day; but still they had in each of those cases to run trial lines, and the money expended in those unnecessary trial lines, if I could have had the topography of the sites which I already knew, would have paid 50 per cent. of the cost of making the map. If I had had a topographic map, even of the sites which I already knew, I could have saved enough in the running of trial lines to have paid 50 per cent., or one-half, of the cost of the map, and that has been demonstrated over and over again on the Arkansas and on other rivers. The greatest waste which I had in that manner was in Nevada. The engineer who went there ran unnecessary trial lines, as the chairman knows. He was the first man to raise an objection to this work; he organized the movement against the topographic work and wasted money in running unnecessary trial lines.

The CHAIRMAN. When an engineer runs his trial lines for his ditch he must be governed by something besides topographic maps, must he not?

Director POWELL. No, sir. Suppose that I have selected the reservoir and the land. That had to be done first. Now I want to know how I am going to get the water from that reservoir to that land.

The CHAIRMAN. Can you select the land before you know definitely where the ditch is to be located?

Director POWELL. I can with a topographic map; otherwise I have got to run trial lines, either one or the other. Without that map I must run trial lines. To make selections by running trial lines is to increase the cost of the work three times.

The CHAIRMAN. Can you select with sufficient accuracy to enable people to locate on the lands?

Director POWELL. I can.

Senator MOODY. In making these topographic maps you run these lines, do you not?

Director POWELL. Yes, sir. I run them with plane tables by methods which we have developed in the Survey. To explain it would require a long trigonometrical statement. Let me further say that in addition to the discovery——

Senator MOODY (interposing). Right here let me ask, can you run a line with such accuracy as to enable the engineer to follow any line without himself running levels and lines in the usual way, with transit and levels?

Director POWELL. Suppose that we have a reservoir at one point, and some land at another point, 10 miles away. I can say from the topographic map that the best line that can be made from that reservoir to that land must run along that hill and meander down that valley, and down that hill, through that valley, to that land——

Senator MOODY (interposing). You could do that with the eye.

Director POWELL. And having done that the engineer ultimately runs over that ground, and from the reservoir site to the lands for the purpose of doing one other thing. The statute demands that we shall furnish an estimate of the cost. The engineer has to go over the ground and determine the nature of the soil, the nature of the excavations which will be required, what amount of cutting there must be in one place, and what amount of filling in another place, and so on, in order to get at the cost of constructing that canal; but the site of the canal is selected from the map, without any trial lines whatever. I have in my office, Mr. Chairman, three classes of men——

Senator REAGAN (interposing). That is the same method that is observed where a preliminary survey of a railroad is made, the details being attended to afterward?

Director POWELL. The first thing is to make the selection, as we would in the case of a railroad survey, by trial lines, or by topographic surveying, ultimately selecting one, and then make an accurate survey of it. I have adopted the method of discovering the sites, which is the cheapest of all. But, Mr. Chairman, the topographic work is an important part of the irrigation survey for other reasons than those already explained, and such reasons are even more potent. The amount of water furnished by a hydrographic basin must be discovered. If a reservoir is to be constructed it must be known how much water can be furnished it annually before its size and the character of its works are determined. To select the lands to be irrigated I must know how much water there is to serve and how much water each acre of land will require; that is, the amount of water and the duty of water. In general, there is more land than the water can serve. Only one-eighth or one-tenth of the country can be irrigated, because there is not water enough to irrigate more. I must find out how much water can be got to serve that land. How would I do this? This was the most difficult and complex problem presented to me when the survey was inaugurated. How could we gauge all the rivers, creeks, and brooks of two-fifths of the area of the United States—all the waters flowing in the streams of that region—in order that works for their control and use might be constructed and lands for them to serve might be selected? There is a vast number of these streams, as will be seen by a review of the entire ground. To gauge one stream means what? It means that we have

to discover the velocity of the current, which varies from shore to central line and which varies from top to bottom, so it becomes necessary to determine the velocity of the current in every part of the cross-section of the stream, because the flow is not uniform, it being greater in the center and less at sides and bottom, but exceeding variable for different forms of cross-sections. Supposing it to be gauged in this manner on one day of the year, that night a rain falls and the stream is enlarged, the entire conditions are changed, the cross-section is larger, and the velocity of the current is greater. So it changes from hour to hour and from day to day, rising with the rains and falling with the drouths.

To find out how much water flows down the stream during the year it is necessary to find out how much water flows in that stream at every stage of its volume, from the lowest water to the highest water. This is done by the use of current meters. Then it is necessary to employ a river-height gauge to determine how high the water is at each hour of trial, and having discovered how much water flows at each stage and how much time it remained at each stage, we are able to determine the total flow of the year. But some years are dry, other years there is great rainfall; so the streams vary from year to year, and their volume in minimum years must be determined, and their maximum volume, and their average volume from year to year. To gauge the flow of each river and brook in the manner which I have indicated would require an enormous outlay of money, so great that when I studied the problem, as I did before the Survey was organized and before it was authorized by Congress, I reached the conclusion that the work could be done in another and cheaper manner, and in a manner altogether more satisfactory. I reached this conclusion after a very careful study of the subject myself and after having submitted it to other gentlemen associated with me. The same conclusion was reached by all the gentlemen except one; that was Captain Dutton. The plan was to make a topographic survey of the catchment basins which should determine with reasonable accuracy their area, with reasonable accuracy their declivities or slopes, and to gauge a few of the streams in the manner which I have indicated and to find therefrom under varying topographic conditions and varying altitudes, and varying rain-falls, the amount of water which could be derived from each square mile of the territory of the basin.

Permit me to make this plain by the use of an illustration which will serve well for that purpose and better than a long discussion of the subject by which the scientific methods might be elaborated. Suppose I wish to know how much water there is running annually from the roofs of the houses of Washington. Shall I put a water-spout on every roof and gauge each one for every day in the year and for a series of years in order to get the mean annual flow? Such was the plan advocated by some of the engineers, but such was not the plan adopted by myself. Now suppose I gauge the amount of water which falls from the roofs of a dozen houses in Washington, or even a less number, so as to get a good fair average of what every square yard of roof surface will deliver during the year. I can then easily determine how much water a square yard of roof surface will furnish during a year; and having found that a yard of surface, for example, on a general average, will furnish a yard of water 30 inches in depth during a year, I have the means of determining the amount of water which any roof in the city will afford by simply measuring that roof. This is certainly a very much simpler and just as satisfactory a method as to put a current-gauge on every water

spout of the city. To do the work of the survey by gauging all the streams would cost an unknown sum, but certainly not less than $10,000,000. So I determined to gauge a few typical streams and measure their catchment areas; that is, to determine the extent of catchment area and to base the computations of water supply upon the factors thus developed and upon the factors derived from the measurement of rain-fall. But it is necessary not only to measure the superficial area of the catchment basin, but also to determine the declivity or slopes of the ground by which the water would be gathered into streams and delivered to the irrigating works. The necessity for determining this element can be very simply explained.

The CHAIRMAN. The hydrographic survey is different from the topographic, to some extent, is it not?

Director POWELL. No, sir. A hydrographic survey is a topographic survey, but something more is added. A hydrographic survey determines the areas by a topographic survey. I was trying to explain that in my illustration of the roofs of the houses. I have to measure the roofs of the houses, from which the area of the roofs, the catchment area, is determined. It is the method of determining the areas which supply these basins. But there is another thing——

The CHAIRMAN (interposing). You have to approximate the area of the basin, do you not?

Director POWELL. It is not sufficient to approximate the area. It is necessary to determine the declivities. That is a problem which seems very simple when it is stated; but you will find that we have to determine the slopes of all the hills for the purpose. Suppose the rain falls over a district of country that is level, or nearly level; in that arid region no great quantity of that water will flow into a reservoir. It will be gathered up so slowly into pools that it will all evaporate. But suppose it is like that of the Hassayampa, of which the dam has just been swept away. Then all the water which falls upon the catchment area, after the soil is once saturated, will immediately be gathered into the reservoir. It is a region of steep declivities. Here is the source [indicating on the map]. Here is Mount Tritle; here are four great mountains encircling the basin. When a great storm comes on those mountains the water rolls down into the basin. They sometimes have storms in that western country which will give 2 inches of rain-fall in two or three hours. The Hassayampa dam drained a mountain declivity of 325 square miles of nearly naked rock. When the big storm came it only required seven or eight hours by my computation to bring the maximum supply of water against that dam. The maximum supply of water against that dam was 6¼ acre feet per second. There was that much water coming down every second for nearly an hour. Provision had to be made for it, and the declivity had to be known in order to construct the work properly. It was not only necessary to provide a proper way to dispose of the surplus water when it came, but also to know how much water could be stored there. If it had been a flat country there would have been no need to make a dam there, for no water would come down; but it being a steep country, a vast amount of water could be collected.

Now to make my illustration from housetops complete, suppose that the flat housetop is covered with a great thickness of sand, so that all the rains falling thereon are absorbed and finally evaporated by the sun. Then from such tops no water can be caught in the spouts. Suppose that others have varying declivities, and that the greater the declivity the less the amount of sand, until some are so steep that no

sand will remain on them. The steep roofs will deliver all their water. Now similar conditions are found in the natural slopes of every drainage basin of the West. Some regions are so flat and sandy that the waters all evaporate, and nothing can be obtained from them; others are so steep and rocky that almost the entire rain-fall is discharged into stream-channels. It is wholly a question of declivities, and we are therefore compelled to determine these declivities. We want areas of catchment basins and declivities of catchment basins. To get these we make a topographic survey, in the cheapest manner that it can be done to be useful to properly solve the problems. The plan, therefore, is to measure drainage basins and determine their areas and declivities, to see what water they will shed in the streams; then gauge a few typical streams with accuracy, and with these facts—and some collateral ones which need not be here explained, as that would complicate the subject too much for simple statement—we have the data necessary to plan the works to control the water, so that it can be put upon the land.

The CHAIRMAN. I have heard it suggested by engineers that in some portions of that arid region there are places where no dam could be safely built, and that those places would be generally indicated by the large bowlders and rocks at the mouths of the cañons, showing that water-spouts had come down with such force as to carry those bowlders through the cañons; and I have heard it suggested—and I want to know what there is in that suggestion—that they would have to avoid those places because of the evidences that water-spouts are likely to occur there. I have also heard it suggested that a good engineer in constructing a dam on those torrential streams would always leave a sufficient waste-way to carry the whole body of water at flood-time, that there should be an ample allowance, so that there would be as large a water-way as there was before the dam was constructed, and that on the ground many things besides the declivities had to be taken into consideration.

Director POWELL. In the first place, as to water-spouts. I hold that the suggestion which they make about water-spouts is valueless. You might as well say you will find the places where lightning has struck and will not build houses in such spots. The distribution of water-spouts is now here and now there. I mean by "water-spouts," tornadoes. Their distribution is not controlled chiefly by the topography of the ground, but by movements in great bodies of air more or less loaded with vapor.

The CHAIRMAN. Now, let me make a suggestion. At Eureka and Panamint Cañons, the former of which has been known about twenty years, there are bald mountains above, where clouds meet and cause these cloud-bursts or water-spouts. In Eureka Cañon the town has been destroyed once or twice, and they have had to build back on the hills to get away from the floods. There have been four or five water-spouts or cloud-bursts in that same place. Panamint Cañon has not been known so long, but there is a similar formation there—bald mountains, the tops of which are very high. Large bowlders have been carried down and land-slides have been produced by these cloud-bursts. We know from observation that they have appeared periodically and that they are liable to occur again; that there are a great many places where they have repeated themselves.

Director POWELL. Let me make an explanation, Mr. Chairman. A tornado is one thing; what is usually called in the West a cloud-burst is another thing. The term "cloud-burst" does not mean anything, really, to a scientific man except a big storm. Those occur in all lands, but they

are peculiarly destructive and remarkable under the conditions you have suggested. We have just as many cloud-bursts in Washington as they have at Eureka or Denver. Let me explain further. Suppose there is a region of country the declivities of which will gather all the water that falls during a great storm suddenly; instead of days, it gathers in hours or minutes, as is the case at Denver. If the declivities are extreme and a great storm comes, the people call that a cloud-burst.

The CHAIRMAN. I have seen a great many of them. I have been in the sunshine, and have seen a dark cloud off over the mountains, accompanied by thunder and lightning, and have seen the people running to the mountains to escape what was inevitable, because they knew the place so well, and in half an hour the water would be 25 feet deep where they had been. The friction of the water on the bottom of the stream would make a column of water that was almost perpendicular; a wonderful sight.

Director POWELL. I have walked before such a one, where a wall of water nearly as high as my head came down a dry stream bed. The region of country most affected by those sudden storms on the face of the globe is the region which I first explored, that of the Colorado River. There the walls of the cañons are from 4,000 to 6,000 feet high, with a labyrinth of cañons running into it from either side. When the rain falls in that district of country the Colorado River is raised, sometimes many feet in one night. The great storms which occur at the headwaters of the river do not fill the cañon as full as the local storms do, because in the local storms the water falls on the declivities, which are like the roof of a house, and is discharged into the river in a few hours.

The CHAIRMAN. Would it be safe to build dams in those peculiar cañons at all?

Director POWELL. I think not. I am afraid the line of my thought is so broken that——

The CHAIRMAN (interposing). I will not interrupt you again.

Director POWELL. I am very glad to have you ask questions. I wanted to say that the topographic map, then, is the chief expense of the hydrographic survey, as the measurement of the roofs of the houses of Washington, which I used as an illustration, would be the chief expense of determining the rain-fall. My hydrographic survey is primarily a topographic survey. The selection survey is a topographic survey. I have to determine catchment areas, reservoir sites, and irrigable lands, and I have to determine the sites of diverting dams and lines of canals. All these are done by the topographical survey, and, in my judgment, in the cheapest possible manner.

Adjourned.

SEVENTH DAY'S SESSION.

WASHINGTON, D. C., *March* 18, 1890.

The committee met pursuant to adjournment.

Present: Mr. Stewart (chairman), Mr. Plumb, Mr. Moody, Mr. Casey, and Mr. Reagan.

FURTHER STATEMENT OF DIRECTOR POWELL.

The CHAIRMAN. Major, you can proceed.

Director POWELL. I attempted at the last meeting to explain the use of the topographic survey in carrying out the purposes of the statute in making the irrigation survey. The things which, under the law, we are compelled to discover are, first, the catchment areas and their declivities, in order that the amount of water can be determined and the method by which that water can be controlled and brought upon the land. It was shown that we not only need the area of the catchment basin, but its declivities, and the topographic survey economically discovers the area and the declivities. The higher declivities are determined in a more general way than the lower ones. The regions of the reservoirs, of the canals, and of the irrigable lands are surveyed topographically with a great deal more refinement than the others. We also have to discover the sites of the reservoirs, and, as I believe, of all practicable reservoir sites, for the purpose of selecting those which are best and most economic, and which serve the lands the best. The second purpose is to discover the sites of diverting dams along the streams, or service dams, as they are sometimes called, and the sites of canals. For this purpose, as there are a great many canal sites to be discovered in any one district, it is necessary to overlook the entire district in order that the best may be found and selected. Having discovered all possible reservoir sites, all possible diverting-dam sites, all possible canal sites, and all possible lands that can be irrigated, it becomes necessary, then, in view of all the facts, so that they may be correlated one to another, to make selections. The discovery of these by the use of trial lines, I stated, would cost at least three times as much as to discover them by topographic methods. They must be discovered by some method or other, and for the purpose of discovering them the most economic method is used. Further than that, it is necessary to determine the volume of water flowing in the streams, and for this purpose it is found, after a careful examination, that this stream-flow can be discovered by a combination of topographic and gauging methods with very much greater economy, and I illustrated that by showing how we would discover the amount of rain which could be gathered from the roofs of a city. I suppose that the hydrographic survey, if we had attempted to gauge each stream, would have cost from four to ten times more than by the present method; so that, altogether, the use of the topographic survey for discovering all these facts in relation to the hydrography—the reservoir sites, the canal sites, and the irrigable lands—very greatly reduced the cost of the work.

Senator MOODY. Will you please describe how you execute this topographic survey for such a purpose?

Director POWELL. Yes, sir; in the first place, we enter a hydrographic basin—we will speak of one basin, as that will illustrate them all.

Senator MOODY. Just select some place.

Director POWELL. I will take the Upper Arkansas, for example. There we measure a base line——

Senator MOODY (interposing). Did you carry on any topographic work there during this last year?

Director POWELL. Yes, sir.

Senator MOODY. Whereabouts?

Director POWELL. Through the basin, from the summit of the mountains in Colorado nearly down to the Kansas line, so that we have covered almost all of the Arkansas basin within the arid region.

Senator MOODY. In this connection, did you have any engineering work done outside of the topographic work?

Director POWELL. Yes, sir.

Senator MOODY. What was that?

Director POWELL. That was to measure the capacity of the reservoir sites, to make plans for dams, and the construction of reservoirs, to run lines of canals on the ground, and estimate their cost. That was the engineering part of the work.

Senator MOODY. How did the topographic work aid that engineering work?

Director POWELL. The topographic work practically discovered all of the reservoir sites and all the canal sites. It also discovered the hydrographic basin—the outline of the hydrographic basin and its slopes.

Senator MOODY. Please give in detail, if you will, the manner of executing that topographic work at one single point where you discovered reservoir sites.

Director POWELL. A base line is measured. From that base line a system of triangulation is projected, which is exceedingly inexpensive, costing, perhaps, at the rate of fifteen cents per square mile. That covers the basin with known points with far more accuracy than it could be measured with chains at a hundred times the cost. Then the topographer determines, at the bottom of the basin its altitude above the level of the sea. He proceeds up the main stream and up its lateral branches with a line of levels, so as to determine the gradients of the streams themselves. As he proceeds in this way up the stream and up the lateral streams, he locates himself from point to point by the known points which are already established by the system of triangulation, stops at this point or that point and finds out where he is at the moment, and plots that upon a plane table which he carries with him. From his station then with gradienters in part and alidades in part, and with other instruments, he determines the altitude of the hills and valleys about him and makes a map of the region on the ground then and there, passing from point to point along the streams, as I have mentioned.

Senator MOODY. What becomes of that map? Does he turn it over to the engineers, so that they can measure and determine the capacity of this basin?

Director POWELL. Ultimately with all the data gathered in its construction. As he goes along he runs grade curves in the valleys, in some places 10 feet apart, but in general in the valleys where irrigable lands are situated the grade curves are run 20 feet apart. Higher up in the mountains they are run 50, 100, or 200 feet apart. It is not necessary to do the work with a great degree of refinement in the mountain regions. Thus he constructs a map as he goes of that drainage basin. When that map is constructed he is enabled to outline upon the map, first, the area and declivities of the drainage basin, and, second, all

possible reservoir sites—the topographer has discovered them—all possible irrigable lands, and all lines of canals from the reservoir sites and the streams to these irrigable lands.

Senator MOODY. Does he form one of a general party, including the engineers, who are running the actual levels and laying out lines?

Director POWELL. No, sir. The work is carried on by three parties—one a topographic party, one a hydrographic party, and one which is working upon the lines and canal sites, making plans and estimating cost of construction. Those are three different functions, which are pursued by three different classes of men. Shall I go on further with an explanation of how the maps are made?

Senator MOODY. Yes; until you show the connection between the topographic work and the engineering and hydrographic work.

Director POWELL. The topographers having discovered the reservoir sites, the canal sites, the irrigable lands, and the basins that are drained, the material is furnished to the engineers and hydrographers. The hydrographers do not go with the topographers, but we select in such a basin some point where one or two typical streams can be gauged, and the hydrographer stops at that station and measures the stream from time to time until he has determined the volume of water flowing in the stream at its various stages. Then he selects a series of points on a series of streams and arranges his instruments in such a way that he passes from one stream to another, visiting them once a day, once a week, or once a fortnight, as the case may be, having stationary instruments which record automatically for a part of the work. Finally the hydrographer has discovered the flow of the stream, and from an examination of the topographic maps which have been prepared, which give areas and declivities, he is able to say what water can be furnished for irrigation and what works are necessary to control it. Having these facts and the sites discovered and the lines discovered, the engineer now enters upon his duty, and he decides that out of fifty reservoir sites twenty of them, perhaps, are the best. Having determined that these twenty reservoir sites are good, having marked the general routes or lines of the canals which must be constructed from these reservoir sites to the lands to be irrigated, he then runs upon the ground the lines necessary to outline the basin with accuracy, cross-sections it to determine exactly how much water it will hold, he then examines the site for the dam, and determines its foundation, length, and height. Having these factors before him—the amount of water which can be supplied to that reservoir and the amount of water which in great storms it must be able to control so as not to be destroyed, all of which is furnished him by the topographers and by the hydrographers,—the engineer's duty now is to plan the works, mark their sites upon the ground, and estimate the cost of their construction.

Senator MOODY. Out of the appropriation of $250,000 how much was assigned to topography?

Director POWELL. About one-half—nearly one-half.

Senator MOODY. And how much to the engineering and hydrographic work?

Director POWELL. The other part—a little bit more than one-half.

Senator MOODY. Can you give the exact amount?

Director POWELL. I can not from memory, but I think, perhaps, I have the data here.

Senator MOODY. How much of the topographic assignment has been expended?

Director POWELL. About seven-eighths of each.

Senator MOODY. That is, seven-eighths of $350,000?

Director POWELL. Seven-eights of the part of the $350,000 which was assigned to topography. I have laid all those facts before this committee heretofore. In the statement I made some time ago I gave the cost per square mile, etc., as you will remember. That is all in my testimony.

Senator REAGAN. One of the points made against this topographic survey is that you have assigned a great deal more money to that than to the hydrographic survey and the engineering work, and that you are making it cost more than it ought. I wish you would let us know how that is.

Doctor POWELL. The engineering work of marking on the grounds the lines discovered by the topographic survey and the sites of the reservoirs and the computation of the cost of the work will, I suppose, require about three-fourteenths of the appropriation.

Senator MOODY. That would be about $60,000.

Director POWELL. Yes, sir; of the last appropriation of $250,000. A larger proportion was used this year because we had not the topography in every locality; but I am speaking of what the plan will be in the future. All this has been set forth to the Appropriation Committee of the House, and is on record. The hydrography will cost, if carried on by our present plan, about three-fourteenths, and the topography, as it is called, will cost eight-fourteenths of the money. That is about the proportion which it will be in the future. That has not been the proportion this year. We chanced this year to know of certain reservoir sites from previous studies of the country. These were already known, and we did not have to go to the expense of discovering them.

Senator REAGAN. While you are on this branch of the subject I wish to present a point which I think will be of interest to the committee. It is alleged that by your plan of a topographic survey it will take many years to complete with a very large expenditure. I have heard the suggestion made before the committee that the cost will be $30,000,000, and that it will greatly delay the development of the project of irrigation. I would like to know what you have to say to that.

Director POWELL. To complete the survey of the arid region, which is about 1,300,000 square miles, and which does not include the subhumid region where some irrigation is practiced, will cost $7,000,000 by following the methods which have been adopted. The time in which it can be completed will depend upon the rate of appropriations. If appropriations are made at the rate of $250,000 per year it will take twenty-seven years; if made at the rate of $1,000,000 per year, as I have recommended to Congress, it will take seven years. But if the methods which we have adopted are abandoned and the more expensive and less satisfactory methods are adopted, it will take five times that amount of money; and if the rate of appropriations should remain the same it will take five times as long. I have explained to the Appropriations Committee, and my statement is on record and I have it with me, that the topographic branch of the work will cost $4,000,000 in addition to what had been accomplished prior to the commencement of the present fiscal year; that the hydrographic survey, as I have planned it, will cost an additional sum of $1,500,000; and that the engineering survey will cost another $1,500,000, making in all $7,000,000.

Senator REAGAN. What is it that will cost $4,000,000?

Director POWELL. The completion of the topographic branch of the irrigation survey for the arid region, not including the subhumid region, for which no estimates have ever been made, will cost $4,000,000 more

for the construction of the maps; but in the construction of the maps we discover all reservoir sites, all canal sites, all drainage basins, and also discover by the same method the data upon which we determine the amount of water which each basin will supply. That will cost for that region $4,000,000. The experience of this year shows that that was a liberal estimate. It was based upon the theory, as explained to the committee, that it would cost from $4 to $5 a square mile. The work this year has cost $3.78 a square mile, and that will carry us to the 1st of July and complete the office work; so that the estimate was not too small, but was quite within bounds. Then I estimated to the committee that it would cost $1,500,000 more to segregate the lands; that is, to run all township and section lines and discover, in Land Office terms, what lands should be segregated, so that we could report to the Land Office the particular lands which are selected under the law. The law compels us to segregate them. The measuring of the reservoir sites and the computation of the cost of works—all this for $1,500,000 more. Then $1,500,000 for the gauging of streams and the work of the hydrographic branch; which makes $7,000,000; $4,000,000 for the discovery of the facts——

Senator MOODY (interposing). That is the topographic work?

Director POWELL. Yes, sir; and $3,000,000 for the other.

Senator MOODY. For the engineering work?

Director POWELL. For the engineering and hydrographic work and segregations.

The CHAIRMAN. As I understand you, the topographic work precedes and is independent of the engineering work, and the engineers simply use the maps prepared by the topographers and obtain the information as to the flow of water from the hydrographers and then they proceed afterward?

Director POWELL. Yes, sir.

The CHAIRMAN. What connection is there between the topographic work and engineering work? Are the two classes of work done by separate forces or by the same force; that is, is the work done by separate divisions or one division? Do the engineers simply take the maps from the topographers when they are done and go on with their work alone?

Director POWELL. The engineers take the data which the topographers have prepared for them. They do not go over the ground to discover reservoir sites, they do not go over the ground to discover canal sites, they do not go over the ground to discover irrigable lands, they do not go over the ground to discover drainage basins or catchment areas. All these facts are determined for them, and they go to the reservoir sites, the canal sites, and the dam sites, and make their estimates of what it will cost to do the work, how the reservoir, the canal, and the dam shall be constructed, and what it will cost. That is the duty of the engineers.

The CHAIRMAN. Will the topography furnish them with data accurate enough to enable them to locate the reservoir sites and the canals without running over the ground with transit and level?

Director POWELL. Yes, sir; except on the lines selected, as I have explained to the committee. The reservoir sites themselves have to have a much more accurate survey, and the line which is selected to take the water from a reservoir site to the land has to have a much more accurate survey.

The CHAIRMAN. What is to hinder the engineer from going upon the ground and locating his reservoir site without the aid of topography? For instance, I go up into the mountains, and I find a stream of water; I follow that stream up, and I find upon it various flat places, without

any engineering at all, and I can see with the eye that I can build a dam there. Then I find that an area of country below in the valley is irrigable. What is to prevent an engineer from first ascertaining about where the water could be taken out at the foot of the mountain, and determining what lands he could irrigate with his level, and without running any trial lines, and then going on up the stream and locating his dam site? After he has determined the location, he has used his level, and has the topographic part done. Why can he not do that without any previous topography—diagnose the stream, as it were, and construct his dam?

Director POWELL. I will explain that. I can make that clear. Here is a stream coming down from the mountain. We wish to store the water from that stream. We might go along that stream and dam the stream itself, and make reservoirs along its course; but when it is possible to avoid it, we never do that. We never build a reservoir on the course of the stream if it is possible to locate it anywhere else.

The CHAIRMAN. That is if it is a rapid stream?

Director POWELL. No matter what kind of a stream it is. To store the water upon the stream itself is to store it where the works have got to be constructed in such a manner that they will withstand the greatest storms. Wherever it is possible, and we find largely that it is possible, we store the water outside of the bed of the stream, making a low diverting overflow dam in the stream itself, and throw the water out on the mesa or valley to one side, so that a torrent coming down the stream can not destroy that reservoir; and the question you ask brings out one of the most interesting things relating to the subject of the storage of water—that is, never to build a reservoir upon the course of a stream when another site can be found. If you wish to construct a reservoir to store the water of a stream of great volume, take the water out by a diverting dam and a lateral canal, and store it in a basin on one side.

The CHAIRMAN. That our miners learned forty years ago in California; I among the rest. We found we could not make our storage reservoirs in the streams without great dams, and the water was diverted through ditches to storage reservoirs, built sometimes right above the placers or on the top of a knoll by throwing up banks around it, always where it would be protected from the floods. That has been the experience in the mining regions. Now, the engineer is a pretty good judge of what can be done in a torrential stream without any topography. I recognize, Major, the convenience in entering into a district of having the topography in advance, because you know then where to go to work, but I do not see so forcibly its practical necessity.

Director POWELL. Mr. Chairman, it is necessary for somebody to see all of that ground before the plan is made; somebody must see it. The engineer must see it, or somebody must see it for him. He must not only see it with his eye, but he must see it instrumentally. No man can properly estimate distances, altitudes, and slopes without instrumentation. Having seen it instrumentally, all that is needed after that is to put it on paper, and if he puts his notes on paper, makes a record and keeps a note-book, it takes just about as long as it does to make a map. The map is all made on the ground right then and there. The map is a note-book, the simplest and cheapest method of keeping the records. There it assembles the facts so that they can be seen as a conspectus and their relations known.

Senator MOODY. What is the difference between the topographic work done under the specific appropriation for topography and the topography connected with irrigation which you have carried on?

Director POWELL. To the topography which we ordinarily do is added for irrigation a more careful determination of the declivities or gradients of the streams; that is all.

Senator PLUMB. Is the topographic survey which you have been making from the Geological Survey appropriations suitable for the Irrigation Survey?

Director POWELL. Yes, sir; except on one point; the gradients of the streams are not so carefully determined——

Senator PLUMB (interposing). What is it suitable for without this addition you speak of?

Director POWELL. For all purposes for which maps are used.

Senator PLUMB. Then all the work you have done for the geological survey of a topographic character, in order to make it adaptable to irrigation has got to be supplemented by something else?

Director POWELL. Yes, sir; but at a cost which is insignificant. Not over 3 cents a mile is to be added to what has been done.

Senator PLUMB. Then you have been doing under this last appropriation practically what you were doing before?

Director. POWELL. So far as the topographic work is concerned; but we have added to that the gradients of the streams. The organization of the Geological Survey, prior to the foundation of the Irrigation Survey, provided that the Geological Survey should make a map of that country. When that map was authorized by Congress a statement was made by me—and the joint committee of the two houses has reported fully on the matter, and I have the report here—that it would take, at the rate at which appropriations were then in progress, thirty years to make that topographic map. When I presented the matter of the use of that topographic map to the committee I explained its importance, its value, for irrigating purposes, and the commission have reported upon that pretty fully, as you will see from a report which I have brought with me. When the matter of the irrigation survey itself was brought before Congress, session before last, I first was called upon, by a resolution of the Senate, to reply to certain interrogatories as to how this irrigation survey should be conducted, and I outlined in my report to Congress just what I have been doing and what I have explained to the committee, and my report has been published by Congress. I explained the use of a topographic map in relation to an irrigation survey as I had explained it years before, and appearing before the Committee on Appropriations to explain what would be done, I said to them that we would have to add something to what we have been doing for the purposes of estimating the cost and segregating the lands; and if appropriations could be made in such a manner that the time of the work could be shortened, and something more added to that—I said a million and a half for the hydrographic work and a million and a half for the engineering work—I said if $3,000,000 be added to the general estimate heretofore made, we can do the whole work, for we are already doing at this slow rate the topographic work necessary; and the committee on considering the matter understood very well—in their report you will see that it was understood—that they were anticipating the appropriation, that is, making larger appropriations to do what was already authorized, and in addition to that, making an additional appropriation to do these additional things. That was understood clearly by the Committee on Appropriations, and is all a matter of record. The topographic survey, therefore, is necessary, or something to take its place. If the trial-line system is to take its place, the total cost of the whole survey will be increased five times. The total cost of the discov-

ery of sites only—that is, a part of it—will be increased three times, but the total cost of the whole survey will be increased five times; and then the topographic map will still have to be made for the Geological Survey.

It must be understood in this connection that I have submitted to Congress a plan for an irrigation survey of the arid lands, which contemplated an examination of the subject only so far as it related to the use of perennial streams; that it was not contemplated to make a survey relating to artesian waters, storm waters, or sand reservoir waters. If the scope of the survey is to be enlarged the estimates must be correspondingly enlarged. It should be further noticed that the estimate was made for the arid lands where irrigation is generally necessary, and not for the sub-humid lands where irrigation is necessary only in unusually dry years. If the survey is to be carried over these sub-humid lands the estimate must be correspondingly enlarged.

Now, gentlemen, the hour is nearly up, and I have hardly started on the subject; but I wish to beg of you one favor in this matter. You have heard two men connected with the Geological Survey who disagree with me, whose opinions are not my opinions.

Senator PLUMB. Who are they?

The CHAIRMAN. Captain Dutton and Mr. Nettleton.

Director POWELL. I have a good many men on the Survey. The men who are actually responsible for selecting the sites entirely disagree with the men who have appeared before your committee, and agree with me, and I want to beg of the committee to hear both sides of this question, and if you are going to interrogate me and my assistants, let those assistants be heard. Mr. Gilbert, who is practically the assistant director of the Survey, who has been associated with me for sixteen years in this work, and who joined me in the first report on the question of irrigation, has a better mastery of this subject, probably, than any other man in the country. Mr. Thompson, who has been with me twenty-one years in all the work, and who has charge of the map-making, is another whom I would like to have appear before you. I should like to have you call Mr. Gilbert, Mr. Thompson, Mr. Gannett, and Mr. Johnson, all of whom have thoroughly studied this subject, and know how to make maps and how to explain them, and are familiar with all branches of this work.

The gentlemen in charge of parties in each branch of the work have a tendency to exalt the importance of the special branch which they themselves are pursuing, and are apt to claim that the bulk of the appropriation should be given to them for their work. They are anxious to accomplish as much as possible, and to do it in the best possible manner, and urge their claims in what I think to be a very proper manner. I am not sorry that my assistants thus become interested in the work; but it is for me to co-ordinate it and to relegate to each branch its due and proportionate part. This is the error which I think Captain Dutton has committed. The magnitude of the work which he performs and its immediate presence before his eyes obscure his vision, and he fails to discover the magnitude and importance of the co ordinate branches.

The CHAIRMAN. Could they not make their statements in writing?

Director POWELL. If so desired.

The CHAIRMAN. Have them make their statements in writing, and present them to the committee as soon as possible. We are occupying a great deal of time, and want to consider some other matters, and if

the gentlemen you have named can make their statements in writing it will expedite matters.

Director POWELL. You sought the opinions of two men who never made a topographic map——

Senator JONES. (Interposing.) It seems to me like a one-sided affair to allow men on one side of this question to come here and answer questions, and now to have the men on the other side put their statements in writing, without giving the committee an opportunity to ask them questions. It is not right. I want to get the whole truth.

The CHAIRMAN. If there is objection to the written statements of course we will have the gentlemen come before the committee.

Director POWELL. I have been diverted from my line of thought by side interrogatories, and I would like to be heard further. The things which I intended to present are not presented yet.

The CHAIRMAN. We will have another meeting as soon as we can get the committee together.

Adjourned.

EIGHTH DAY'S SESSION.

Washington, D. C., March 21, 1890.

The committee met at 10.30 o'clock a. m.

Present: The chairman, and Senators Reagan, Moody, and Casey.

STATEMENT OF G. K. GILBERT, CHIEF GEOLOGIST OF THE U. S. GEOLOGICAL SURVEY.

Mr. GILBERT. Is it your desire that I make a statement, or that I shall answer some specific questions?

The CHAIRMAN. The committee desire to ascertain from you your opinion as to the connection between the engineering survey for the purpose of irrigation and the topographic survey, and whether the topographic survey is a necessity and must precede the engineering survey. You can go on and make a statement on that subject, giving the relation of the two surveys, the dependence of one upon the other.

Mr. GILBERT. It is my opinion that the information obtained by the topographic survey is essential to good results from the engineering survey. If the same information is obtained by other methods the cost will be relatively great; if it is not obtained the engineering survey will fail to achieve the best results. The topographic survey should precede in each locality.

The function of the irrigation survey, as a whole, is three-fold, as determined by the law. It has first to determine what land shall receive the scant water of irrigation; second, to plan the best system of works for distributing the water to the land, and third, to plan the best system of reservoirs for storing the water which falls in a drainage basin outside the period of irrigation. For each locality, for each drainage basin, as a rule, these three questions have to be considered together. They are so intimately related that they constitute a single complex question, which has to be determined for each locality; nevertheless each one of the questions is in itself complex.

In order to make the best selection of land it is necessary to know what tracts of land are available for the purpose of irrigation; that is, what

tracts of land belonging to a district lie so level that the water can be conducted over them for the purpose of irrigation, and what are the areas of these tracts. It is necessary in selecting from among such tracts to consider their climatic conditions; in some cases there are great differences in climate. It is necessary to consider the soils and subsoils. It is necessary to consider the local duty of the water. It is necessary to consider the waste of water incident to transfer from the source of supply, that is, the distance from the source of supply with reference to the question of waste; and it is necessary also to know the amount of water which is available for some one or more of these districts, that is to say, the annual run-off of the drainage basin. In order to plan the best system of distribution it is necessary to know the positions of the tracts of land which may be irrigated with reference to the reservoirs in which the water for that purpose may be stored. These relations must be known horizontally and vertically, and the character of the intervening country must be known. It is necessary also to estimate the cost of constructing works for distributing the water, and the cost of maintaining such works. It is necessary to estimate the waste through evaporation and seepage by different systems of work, and it is necessary, in order to determine the magnitude of the works, to know the run off of the basin.

Speaking in a very general way, a reservoir can be made anywhere; but there is a great difference in expense, and the really available or practicable sites are those where a relatively small dam will create a reservoir containing a relatively large amount of water, and such sites may be scattered throughout the basin. In determining the question of reservoir sites it is necessary usually to consider whether there shall be a single reservoir or a small number of reservoirs low down in the basin or a larger number of reservoirs on the minor streams pertaining to parts of the basin. In order to make a comparison of these and to plan the best system of works it is necessary to estimate the cost of works, at least roughly, at the various places, and the cost of maintenance, and to consider the waste through evaporation or seepage; these differ with altitude and other conditions, and also with the form of the reservoir. It is also necessary for the other purposes; that is to say, where a reservoir site commands only a portion of the basin, the water which can be stored in that reservoir is only the water which flows through or past that portion of the basin. So, for the study of the problem of reservoir sites it is necessary to estimate with a good degree of approximation not only the run-off of the entire basin, but the run-off of parts of the basin.

Now, in this plexus of factors there is one which is very important; many of them are important, but there is one that is especially important and which is at the same time especially difficult; that is, estimating and determining the run-off. That may be determined, theoretically, at least, in various ways. In the first place, it can be measured directly; the streams can be gauged and their heights at various times can be observed for a period of years, and in that way the amount of water which runs off can be actually measured. For large streams the observations of one year give valuable information; the observations of two years may perhaps suffice for some purposes; but for small streams, in a region of very irregular precipitation, a greater number of years of observation is necessary. There are certain things besides the average annual run-off that need to be known. With reference to the determination of the amount of land it is advisable to put under ditch, the minimum run-off should be known. With reference to the construction of

head-works and canals and dams that will stand against all floods that may come, it is necessary to know the maximum run-off, and it is especially necessary to know the maximum rate of run-off for this purpose. It is necessary to know separately the run-off of each stream that may be separately used in irrigation, and it is necessary to know separately the run-off of each catchment area the water of which may be separately stored.

The direct measurement of the run-off is, in my judgment, a very expensive matter. There must first be determined by a series of gaugings how much water runs off at each stage, and observations of the height of water must then be made and recorded for a series of years. For this purpose it is necessary to keep permanent observers, and such observers can not maintain continuous observations of any considerable number of streams. In my judgment the expense would be not far from $1,000 for each such determination, carrying it on for a sufficient number of years to make it of practical value.

Senator CASEY. What would you consider a sufficient number of years to make it of value?

Mr. GILBERT. That would depend upon the size of the stream.

Senator CASEY. Well, generally.

Mr. GILBERT. I think on an average three or four years would be necessary; but that would not suffice for a great number of small streams. In the case of large streams you could——

Senator CASEY (interposing). Would observations for three or four years determine the maximum and minimum?

Mr. GILBERT. No, sir; not in small streams. In the average run of streams the maximum and minimum occur only at irregular intervals, which may be short or long. That would be a matter more or less of estimation, even after a long series of observations.

Senator CASEY. You spoke of it as necessary a while ago.

Mr. GILBERT. It is important. It is necessary to determine the best works.

Senator CASEY. That would probably take eight or ten years' observation?

Mr. GILBERT. Yes, sir; it would bring the cost into competition with the gain to be acquired through the irrigation of the land.

The CHAIRMAN. It is now twenty-nine years since there was a winter similar to this last winter in California and the country west of the Rocky Mountains.

Senator CASEY. Does that remark go back to last summer and include the whole year?

The CHAIRMAN. Yes, sir; it includes the whole year. There was a very dry year twenty-nine years ago, 1861–'62, and this is 1889–'90.

Senator CASEY. So that if this information as to maximum and minimum run-off were ascertained, it would take a long series of observations?

The CHAIRMAN. What is the difficulty in allowing the inhabitants or inducing them to keep a sufficiently accurate gauge of the water for practical purposes? Could not some arrangement be made with the people living in that region to keep a record which would be sufficiently accurate?

Mr. GILBERT. That is the practical method of ascertaining the greater part of the run-off—to gauge the streams through experts and then employ local observers to watch the rise and fall. That is applicable only to the districts that are actually occupied by settlers now. There are great unsettled regions where the run-off would have to be

determined in order to construct the best works, and these would have to be occupied——

The CHAIRMAN (interposing). Take, for example, the districts in Nevada that are actually occupied; are they not index localities that will do for the unoccupied districts?

Mr. GILBERT. I think so. I was coming to that——

The CHAIRMAN (interposing). So that the Government would not have to go to the expense?

Mr. GILBERT. I was speaking of the method of gauging the water in the streams. That method leads to large expense, in my judgment. The number of measurements that would have to be made in order to consider thoroughly the whole problem of land areas and of reservoir sites would be as much as twenty thousand, leading to an expense that would go into the tens of millions. Now, there are several indirect methods of reaching the result, and I would like to speak of three of these. In the first place, it is possible, usually, by an examination on the ground, to determine what is the magnitude of the flood channel of a stream, and then, by considering the cross-section of the channel in connection with its declivity, it is possible to estimate the rate of the maximum discharge.

The CHAIRMAN. An engineer can do that?

Mr. GILBERT. Yes, sir; and every one makes a crude estimate. When one sees a place where water has run, he thinks "Some time here has been a large stream." The engineer can measure the gradient and the cross-section, and can give an estimate of the rate of run-off in the time of the most severe storm, which will be valuable. In a humid region the rate of run-off is well related to the annual discharge. If we were dealing with a humid region instead of an arid region we might, by a consideration of the magnitude of the storm channels, make an estimate of the annual discharge which would be really valuable; but in the arid region the precipitation is so irregular that this is impossible. I have crossed on the Amagosa Desert a river-bed that is a mile broad. There was no water when I crossed it, and had probably been no water for many years, but at some time there was a great stream; yet that channel runs into Death Valley, and there is not enough water flowing through it annually on an average to keep the bottom of Death Valley wet.

The CHAIRMAN. I have been there.

Mr. GILBERT. So the study of channels in the arid region will not suffice for the determination of the annual run-off of the streams. Another indirect method is by analyzing the features that go to make up run-off, and then measuring the factors and putting them together by computation. We know that the run-off depends, in the first place, on the rain-fall. Now, if we can tell what percentage of the rain-fall escapes, and measure the rain-fall, we have our problem solved. The quantity that escapes depends particularly on two things—the declivity of the surface, or the rapidity with which the water runs, and the constitution of the surface or the soil. Some soils shed water; others hold it and yield it to evaporation.

Senator REAGAN. Now, this is all very interesting; but it is not the point we are trying to get at at all. We want to know, as I understand it, whether a topographic survey is necessary as a means of providing an irrigation system, or whether that can be done more cheaply and quickly by an engineering and hydrographic survey.

Mr. GILBERT. If the Senator will pardon me, I was intending to speak to that point.

The CHAIRMAN. Be as brief as you can.

Senator CASEY. We have been over all this two or three times, and have become very familiar with it, and the practical question Senator Reagan suggests is what we wish to consider.

Mr. GILBERT. The practical method depends on the third method of getting the run-off. The second method, which I have just alluded to, is impracticable, because of the difficulties of understanding the conditions and putting together the various elements.

The third method is one of analogy. In the same general district we have the same general rain-fall at the same altitudes; that is, the general rain-fall varies with the altitude in the same district of country. If we have two drainage basins in the same district of country at about the same altitude, having the same character of surface as to declivities and as to soil, then the run-off from those two basins will be proportionate to their areas; and working on that principle, it is possible to determine the run-off by, in the first place, actually measuring the run-off from certain basins taken as types, and then measuring areas and declivities and examining soil conditions of any other areas of which we wish to know the run-off.

The soil conditions are usually similar through wide belts of country, or, more strictly, their variation is in sympathy with the variation of declivity. Surfaces of gentle slope are more receptive, and steep surfaces less, so that classification of catchment areas by declivities is also largely classification by soil conditions. The measurement of areas and declivities and the determination of the general altitude are the functions of the topographic survey. In my judgment the division of the work into (1) a hydrographic survey which shall determine by gauging the run-off of types of basins, and (2) a topographic survey, has the additional advantage that it indicates the reservoir sites which are to be considered; that it indicates the tracts of land which lie in such shape that they are susceptible of irrigation, and that it indicates the alternative routes for canals and the alternative sites for the headworks of canals to be used in conducting the water to the irrigable lands.

The CHAIRMAN. If an experienced engineer, having general information with regard to the storms that occasionally occur in a given section of country, were to proceed into a drainage basin, follow up the streams, and ascertain the places that are suitable for reservoirs, etc., after having, of course, taken into consideration the general area of the basin by observation, its declivities, etc., what would prevent him from locating those reservoirs and segregating the irrigable lands from the other lands, and doing all that work, with the maps that are already collected, without waiting for the topographic survey to precede him?

Mr. GILBERT. There is a class of streams——

The CHAIRMAN. Could that be done at all?

Mr. GILBERT. It could be done with reference to a certain class of streams, in which the catchment areas lie so high that the climate is unsuited to agriculture, so that the streams will have to be handled low down on their courses, of necessity, and where there are existing good maps; but even in that case the engineer would need to go over the ground, in order to satisfy himself that he has the best system of reservoirs—that the system he adopts will not some time have to be reformed. He will have to go over the entire field thoroughly to discover the available reservoir sites, in my judgment. Where there are maps in existence exhibiting the available reservoir sites that is not necessary; he can discover those that need to be considered from the maps; but in general existing maps do not serve that purpose.

The CHAIRMAN. Are the topographic maps sufficiently accurate to locate the reservoir and estimate the quantity of water the reservoir would contain?

Mr. GILBERT. The topographic map would give only a crude idea of the quantity of water the reservoir would contain, not a sufficient estimate for final comparison; but it would give an amply sufficient estimate of the area of the catchment basin, and through that, with the aid of such a gauging system as I have mentioned of the amount of water which would come to that point, it would give a preliminary estimate of the reservoir.

The CHAIRMAN. Would it not be sufficient for general purposes to have a general estimate of the catchment basin, with a gauging system carried on by the inhabitants, after the first instance? Would not that be sufficient for ascertaining the amount of water for practical purposes?

Mr. GILBERT. In my judgment, for practical purposes it is necessary to examine the country tributary to each site or storage basin under consideration in order to ascertain the run-off, and such examination is most economically made by a general work which covers the whole hydrography——

The CHAIRMAN. (Interposing.) Can not an engineer make that examination?

Mr. GILBERT. Yes, he can make that examination, but he can not make it as cheaply as the topographic survey can. A differentiation of functions comes in here. The work of the topographer and the work of the engineer are, to a certain extent, the same. They use the same instruments; they make maps, contour maps; but they work on different scales, and when a man who works with one scale, be it large or small, is diverted to do a piece of work on another scale, he works at a disadadvantage.

The CHAIRMAN. Which is the larger scale, that of the engineer or that of the topographer?

Mr. GILBERT. The engineer's is the larger scale. The engineer, in order to make his estimate of cost, etc., needs to go into minutiæ.

Senator REAGAN. What is meant by a smaller scale?

Mr. GILBERT. A smaller map for the same area.

The CHAIRMAN. Then, as I understand you, the topographic work would have to be done over again in order to get sufficient data for practical work?

Mr. GILBERT. Yes, sir. On every site of an irrigation works—every site of a reservoir, every line of a canal—a special survey would have to be run. A topographic survey, upon its small scale, and made in the rapid manner that belongs to a small scale, will not afford the data for final estimates as to cost. It serves as a reconnaissance for all those purposes.

The CHAIRMAN. What use would an engineer, locating reservoirs and laying out ditch lines, make of the topographic survey if it had preceded him, leaving the hydrographic survey out of the question?

Mr. GILBERT. He would, in the first place, know with a fair degree of approximation the height above the stream of the land to be supplied with water and the point of the upper portion of the stream at which the water would necessarily have to be taken out in order to be carried to that land. He would be enabled to consider alternate points for diverting the water without running trial lines. He would know where to direct his final survey and how to determine his general course.

Senator MOODY. Mr. Gilbert, is a topographic survey an observation

survey in advance of the definite and particular survey that is necessary in order to locate practically these works that are indicated?

Mr. GILBERT. Yes, sir.

Senator MOODY. A topographic surveyor is ordinarily and usually an engineer, is he not?

Mr. GILBERT. The two classes of work are branches of the same profession, but in general the topographer has a different range of information.

Senator MOODY. In organizing an effort to put a certain region of country under water, that is to establish a system of irrigation, would you organize two parties, one to go in advance of the other and make these observations, or would you organize one party, who would make the observations—a topographic map, or what is its equivalent—and then proceed after they had done that to make the detailed measurements and observations and all that is necessary to locate the reservoirs and carry the water to the lands?

Mr. GILBERT. I would organize two parties, and let one precede the other, even if their work could be carried on together. Even if one did not need the work of the other I would organize two parties. It has been found in the history of Western exploration and survey (changing gradually from exploration to survey) that it was necessary to have different lines of work separately performed. In the original Pacific Railroad explorations all kinds of observations and surveys were carried on together. The resources of the country did not permit cutting up into small parties, and it was necessary to travel in one body. The topographers, the engineers, the naturalists, all went together; it was all reconnaissance. Afterward, when the Hayden, the Powell, the King, the Wheeler surveys were organized, those methods were adhered to at the start, but were finally departed from. Eventually there was one party for triangulation, another for topography, another for geology, traveling in the same district, but traveling independently, because it was advantageous to have the movements of each controlled by the particular work to be done.

Senator MOODY. Supposing you were starting out originally to open up a drainage district, what would be your plan? Would you not first make these observations that you speak of, and then follow them up with a survey or measurements and the requisite engineering work, just as you would in locating a railroad through the country?

Mr. GILBERT. Yes, sir.

Senator MOODY. In other words, you would select the general plan by observation, by certain preliminary measurements, and then carry it out by detailed work. Would that be it?

Mr. GILBERT. Yes, sir.

The CHAIRMAN. Have you any further observations to make?

Mr. GILBERT. I have not.

The CHAIRMAN. Before you go I wish to inquire what your profession is.

Mr. GILBERT. I am a geologist.

The CHAIRMAN. Are you engaged in the Geological Survey?

Mr. GILBERT. I have been engaged in the explorations and surveys of the Government since 1871. I have been mainly occupied in geological work, but have done some geographical work and some surveying, and I spent one year in the study of irrigation problems in Utah.

The CHAIRMAN. What position do you occupy in the Geological Survey?

Mr. GILBERT. I am Chief Geologist. I have charge, under the Director, of the geological work.

Director POWELL. Mr. Chairman, I would like to have you ask Mr. Gilbert the relative cost of doing the work of the irrigation survey with the aid of the topographic survey and without it.

THE CHAIRMAN. Mr. Gilbert may answer that question.

Mr. GILBERT. Mr. Chairman, I have not given sufficient consideration to that matter to give a quantitative estimate of the cost. It is my decided opinion that the cost would be much greater, several times greater, if the determination of the sites, etc., were made by trial lines and by reconnaissances of the engineers, instead of being made by a general topographic survey.

Senator MOODY. Will you state, as briefly as you can, the difference between what you call trial work, the running of trial lines and observations by the engineers, and the topographic work?

Mr. GILBERT. That is easiest illustrated by considering a railway survey. The railway engineers, wishing to go from one point to another, inquire of the people as to routes, if they have no personal knowledge of the country themselves, and in that way learn of several routes that may be compared. They follow out each one, making a line survey, similar to the survey that they would make for the location of the road for the purpose of seeing where the opportunities are. Having done that they then select one line as best, modify it perhaps, and make a final survey. Now, in a country where there has been a topographic survey they run no trial lines. Take, for instance, the Appalachian regions when the topographic work of the Survey is in progress. Where these topographic surveys have been made the railway engineers study the maps, and by such studying are able to compare the possible routes, and usually to eliminate from consideration all but one and go to that directly.

The CHAIRMAN. Is there not a difference between a railway survey, which passes through the country over the lowest elevations, and a survey for the purpose of conducting water, which is arbitrary and which must be run where the elevations will permit? Does the engineer surveying for the purpose of irrigation require those comparative trial lines? Must he not go into a valley and ascertain by his eye and by his level where water will run around the valley, and is not that the trial line that he has got to run? He has got to follow that line if he is going to cover the land below with water; he has got to follow lines that are easily found.

Mr. GILBERT. In simple cases, but not by the eye. He must do it by levels. The eye always deceives. A ditch always runs up hill, apparently. But where the problem is to consider whether several streams shall be handled together for purposes of irrigation, or whether a stream shall be taken out at some low point on its course or at some higher point, by a route that offers better facilities for construction, then a reconnaissance of some sort is necessary. If it is not made, then the most economical route may not be the one that happens to be found.

The CHAIRMAN. In that case would the topographic survey show the engineer the levels and the difficulties of construction with sufficient definiteness to relieve him from the obligation of examining the route personally? If he is going to make estimates, has he not got to go over the ground anyway?

Mr. GILBERT. It will eliminate all the possibilities, except one or two.

The CHAIRMAN. Would it be very difficult, after you had the point where the water could be diverted, to ascertain the possibilities as to where the ditch might be run? Could not that be determined by levels

very readily, without much expense, and could not all the possibilities of the stream be determined by levels at a minimum expense?

Mr. GILBERT. Yes, sir; but the topographic survey is a determination with a very small expense indeed. While it figures up in the aggregate to some millions of dollars, its rate per unit is very small.

The CHAIRMAN. Is not a great proportion of the expense of the topographic survey for work in countries where you can not utilize the land for irrigation and where you can not utilize the waters for that purpose? Is there not a great deal of surveying outside of the particular basins that can be utilized for irrigation purposes?

Mr. GILBERT. As I understand it, the future irrigation of our arid region is going to be distributed over its whole extent. It is going to include districts where a few years ago the thought of irrigation did not occur, but where storm waters can be used; and the general survey is going to be one of the means of indicating those districts.

Senator MOODY. So that the topographic survey will get the whole country ready for irrigation in the future.

Mr. GILBERT. Yes, sir.

Senator REAGAN. So far as you go, does the topographic survey include the whole country or select districts?

Mr. GILBERT. As I understand the work it has been begun in various States and Territories in basins where there is immediate need for the determination of these irrigation questions. The selection of tracts for initial work has been made with reference to the earliest needs of the greatest number of people.

Senator REAGAN. And that may be extended as necessity arises?

Mr. GILBERT. Yes, sir. But at the same time complete blocks of country have been surveyed; not small areas of a straggling nature, but the general plan has been to complete the whole area. The beginnings of the work, however, have been made where the present need was most urgent.

The CHAIRMAN. Does your topographic survey leave marks on the ground indicating altitude and other signs which can be followed by the engineer?

Mr. GILBERT. No, sir.

The CHAIRMAN. They leave nothing on the ground?

Mr. GILBERT. They give the indications of altitudes of points which can be found; of points that are otherwise fixed; for example, the junctions of streams, the crests of hills, etc.

Senator REAGAN. When you get that initial point you take the map and it shows you?

Mr. GILBERT. Yes, sir.

The CHAIRMAN. If it was not at the point where you wished to locate your reservoir or your ditch it would be necessary to have an engineering survey from that point to ascertain the location of hydraulic works, would it not?

Mr. GILBERT. I do not understand you.

The CHAIRMAN. When you get a fixed point you have got to go from that with the engineering survey to ascertain the other point, have you not?

Mr. GILBERT. If we have indicated on a topographic map a piece of plain country, indicated by contours far apart, and beyond that we have a steep hill, indicated by the contours close together, then the contour which skirts the bottom of that hill is the contour indicating the upper portion of that plane surface, the portion to be commanded by the ditch, and that is something of practical value, even if there is no absolute

point fixed. It is the edge of that plain. I do not know that I fully understand you.

The CHAIRMAN. To determine a definite point at which to locate your reservoir you will have to find a known point. The map will not show you.

Mr. GILBERT. The expression of the map is through contours.

The CHAIRMAN. I know the expression; but does it not require actual engineering to find other given points definitely?

Mr. GILBERT. Yes, sir.

The CHAIRMAN. After you have the initial point from your topographic survey, it requires engineering to determine other points?

Mr. GILBERT. The topographic survey gives the position and height of definite points with the degree of precision or the map, whatever that may be, and if you compare any two of these points by means of the contours you have their relative heights. Take the upper edge of a plain that may be irrigated. You have the height of that with reference to the stream at various places, and by tracing the proper contour line you have an approximate idea of the course of the lowest possible canal route.

The CHAIRMAN. By what instruments do you ascertain altitudes?

Mr. GILBERT. That is ascertained in different parts of the country by a variety of instruments. In the present work of the Survey it is obtained chiefly by angles of elevation and depression; but it is also ascertained for altitudes that are not very essential to the work of irrigation by means of barometers. It is also ascertained along the lines of principal streams, I understand, in the present topographic work, by spirit leveling, but the other gentlemen present are better qualified to explain that than I.

STATEMENT OF ALMON H. THOMPSON, IN CHARGE OF TOPOGRAPHICAL DIVISION OF U. S. IRRIGATION SURVEY.

The CHAIRMAN. Mr. Thompson, what is your profession?

Mr. THOMPSON. I am a geographer, in charge of the topography of the Irrigation Survey.

The CHAIRMAN. Will you state to the committee whether a topographic survey is necessary to an engineering survey for the purpose of irrigation, confining yourself in as short space as you can to that exact point?

Mr. THOMPSON. A topographic survey is the cheapest and most accurate way of obtaining the facts necessary to plan a system of irrigation works for any natural district or drainage basin, and the results can be given to the people in the shortest time by this method. There are three well-defined phases or steps taken in engineering work.

The CHAIRMAN. Those steps have been explained a good many times to the committee. State what use an engineer would make of a topographic survey in a given district?

Mr. THOMPSON. It is supposed by the topographers and most engineers that it will furnish him all the data necessary for a reconnaissance; that he obtains in that reconnaissance most of the data for his lines, which he then runs. It is not supposed that it will furnish him data sufficient to make estimates of construction, such as cuts and fills. It is supposed that he will have to do that particular step of the work afterward. But it is supposed that it will furnish him with all informa-

tion necessary for the first two steps, with the exception of now and then a single trial line.

Senator CASEY. Suppose the data had not all been ascertained, what course would he pursue to obtain that data; would it be the same course that the topographic survey had already pursued?

Mr. THOMPSON. Yes, sir; if he wished to obtain it over an extended area of country. If he wished to obtain it as the topography is obtained in a line survey, for a few feet on either side of the trial line he might run, he probably would not cover the whole country with his map.

Senator CASEY. He would cover only that region that he had particularly under his eye.

Mr. THOMPSON. Yes, sir. But the practice of the best engineers of the present day seems to be to obtain the topography of the whole country, especially in regard to irrigation work; and in other countries——

The CHAIRMAN (interposing). In what other countries do the topographers precede the engineers?

Mr. THOMPSON. In India, and to a certain extent in California, in cases that have come under my observation, and in countries where new irrigation works are located.

The CHAIRMAN. Have you any reports from the Indian surveys where they insist on topography preceding the engineering surveys?

Mr. THOMPSON. No, sir; I have no reports, but such reports are in the library of the Survey.

The CHAIRMAN. You have no reports showing that?

Mr. THOMPSON. No, sir; nothing in my hands. But there have been topographic surveys conducted in India for a long time, and these surveys are made use of by the engineers in constructing new works. The engineers of that country, as in this, I believe, obtain maps to begin with.

The CHAIRMAN. In southern California you say the topographic surveys precede the engineering surveys for hydraulic purposes. In what instances?

Mr. THOMPSON. I was trying to think of the particular instance. A year ago I was in San Francisco and an engineer came to me to ask me about the topographic work, stating that he had been employed by some company in San Diego County to construct works for irrigation purposes, and that his first step was to make a contour map of the area with intervals of 10 feet.

Senator CASEY. He made that in the particular region in which he was working?

Mr. THOMPSON. Yes, sir. I think he said the area of his map was about 10 square miles.

Senator CASEY. Was it any more expensive for him to do that work for the purpose he had in hand than it would have been if it had been done by a preliminary survey by the State?

Mr. THOMPSON. In my judgment it was much more expensive than a survey on a general plan.

The CHAIRMAN. Would he not make it more accurate having in view the objects to be attained, and would he not direct the survey to the attainment of those objects?

Mr. THOMPSON. That is a hard question to answer. If, on the general survey a map was made having the same contour interval and detail, I think it would be quite as accurate as he would make it.

Senator REAGAN. Would not the answer to that depend upon whether the survey was made with greater or less detail?

Mr. THOMPSON. Pardon me. I said if the map was made with the same contour intervals, which means with the same details.

The CHAIRMAN. Would not the engineer, in making such a contour survey as he deemed necessary, locate marks on the ground which he could use in his survey, and which would not be found in a general topographic survey?

Mr. THOMPSON. It is possible that he might make some special marks with reference to his construction work. Our surveys are all connected with the Land Office surveys. The Land Office corners are marked every half mile, and our surveys are connected with the Land Office work; so that the Land Office lines can be drawn upon our maps, and the connection between the topographic work and the Land Office work be determined.

The CHAIRMAN. Are the Land Office marks extended into the mountains where there is no market for the lands?

Mr. THOMPSON. My remark relates to areas where the Land Office survey extends.

The CHAIRMAN. They do not extend into the desert lands?

Mr. THOMPSON. They do survey large tracts that are desert lands. The State engineer of California, when he was planning a system of works for that State, made topographic maps with contour intervals of 10 and 20 feet and carried the work over a portion of the State, although he was not planning a reservoir system but only canal lines to use the waters running in the streams during the time of irrigation.

Senator MOODY. Have you charge of the work of the Topographic Survey as well as the Geological Survey?

Mr. THOMPSON. Only of the irrigation branch.

Senator MOODY. In what regions of country has the work been conducted under last year's appropriation?

Mr. THOMPSON. In the Arkansas Valley, in Colorado; in New Mexico, on the Mora and Gallinas Rivers, in the region of Santa Fé and Las Vegas; and on the Rio Grande, in the region of El Paso; in California, in the region about Lake Tahoe, on the head-waters of the American and Uba Rivers, and the northern branch of Stanislaus, and the head-waters of the Truckee and Carson Rivers; in Montana, on Yellowstone Lake and along the Yellowstone River, and in southern Idaho along the Boisé and Snake Rivers.

Senator REAGAN. And on Sun River?

Mr. THOMPSON. No, sir. My work did not extend to Sun River. That was done under the engineers.

Senator MOODY. What work has been done by the Topographic Survey in connection with the engineering work under this irrigation scheme and appropriation?

Mr. THOMPSON. Over the same areas?

Senator MOODY. Yes.

Mr. THOMPSON. The engineers were working in the Arkansas River drainage basin in Colorado and about Lake Tahoe, in Nevada and California.

Senator MOODY. Was that in connection with the topographic work?

Mr. THOMPSON. The topographic work was not immediately connected with the engineering work. The engineers were engaged, as I understand, in surveying reservoir sites.

Senator MOODY. Where was the engineering party under Captain Dutton?

Mr. THOMPSON. He had general charge of the whole engineering branch.

Senator MOODY. Whereabouts did the engineers follow and use the topographic work?

Mr. THOMPSON. In no case that I know of. The topographic work had not been finished.

Senator MOODY. All that the engineers did under last year's appropriation has been done independent of topographic work?

Mr. THOMPSON. Of our completed work, as I understand it. They have called on us for our field-notes in many instances.

Senator MOODY. Were you able to furnish them any field-notes of your topographic survey?

Mr. THOMPSON. I think none that were worked up so that we would be willing to say that they were reduced the best we could do. We have furnished them preliminary notes, always stating that fact. We have been engaged on office work in the reduction of our observations but a short time. Of course the field-notes given were in a crude state.

Senator MOODY. Then, so far as the work has progressed under last year's appropriation, the topographic work and the engineering work for irrigation purposes have been carried on separately?

Mr. THOMPSON. Yes, sir; distinct organizations.

Senator REAGAN. Do you mean to be understood that the engineers have not made any use of the topographic survey in the engineering and hydrographic work?

Mr. THOMPSON. Under this last appropriation?

Senator REAGAN. Yes, sir.

Mr. THOMPSON. I do not know of instances, except information that they have obtained from our field-notes, from questions they have asked and photographs of field-work that have been given them. The maps have not been completed.

Senator REAGAN. Have you furnished them any?

Mr. THOMPSON. Not yet, sir; because they are not constructed. We have not finished them.

The CHAIRMAN. The hour is up.

Director POWELL. Mr. Chairman, I would like to have five minutes' time. Neither of the gentlemen who have been speaking has seemed to fully comprehend what the committee desire, and I would like to have five minutes of your time.

The CHAIRMAN. There will be another meeting as soon as we can get the committee together, and you shall be heard.

Director POWELL. That is satisfactory.

The committee thereupon, at 12 o'clock m., adjourned, subject to the call of the chairman.

NINTH DAY'S SESSION.

WASHINGTON, D. C., *March* 22, 1890.

The committee met at 10.30 o'clock a. m.

Present: Mr. Stewart (chairman), Mr. Moody, Mr. Gorman, Mr. Reagan, and Mr. Jones.

STATEMENT OF WILLARD D. JOHNSON, TOPOGRAPHER, U. S. GEOLOGICAL SURVEY.

The CHAIRMAN. What is your profession or occupation, Mr. Johnson?

Mr. JOHNSON. I am a topographer. Under the general direction of Professor Thompson I have charge of the topographic work in the Division of the Arkansas River Basin—of the portion of that basin lying west of the Kansas line.

The CHAIRMAN. The present inquiry will be directed to the question of the connection between the topographic survey and the engineering survey for purposes of irrigation, and of whether and, if at all, to what extent, the engineering survey is dependent upon the topographic survey. Please confine yourself to that exact question. We have been over the general ground sufficiently.

Mr. JOHNSON. So far in the Arkansas Basin, there has been little connection between the topographic and the engineering surveys because the engineering survey has entered upon its work in this field in advance of the completion of work by the topographic survey. The outcome of a topographic survey is a map and every step toward that end has its place in a system. The data of field work, if considered separately, necessarily appear fragmentary and incomplete. The parts must be adjusted and co-ordinated by office work. In such work we are now engaged. The area surveyed was large—22,000 square miles, and the map sheets covering all of that area are now nearing completion. The topographic work began in the fall of 1888, and was carried uninterruptedly, with gradually increasing field force, through the following winter, the following spring and summer, and well into the succeeding winter—the winter just ended. Office work then began, five months ago, upon the whole mass of this material. Engineering surveying was entered upon early in the summer of 1889.

In this basin I had charge of the topographic survey only, under the direction of Professor Thompson; within the same limits there was also an engineer—a division engineer—in charge of the engineering survey, under the direction of Captain Dutton.

The CHAIRMAN. Who was the engineer in charge of that work?

Mr. JOHNSON. Mr. Bodfish. From beginning to close of his work I was in continuous receipt, from this division engineer, of requests for maps, for topographic maps, or for map data of any character. These calls upon me for map data were continuous, urgent, and annoyingly persistent—annoying for the reason that I have mentioned, that such data as I had must, until we should have fitted together the mutually dependent parts in office work, necessarily appear to others fragmentary, scarcely intelligible and misleading.

Mr. Bodfish understood this, yet insisted, very reasonably I think, that he nevertheless must have maps, that without them he could do little, and that little at a disadvantage. I was finally directed to furnish

him with photographs of certain unadjusted pieces of map work. I regretted the necesssity for this as I knew that he could not fully understand them, that only those to whom they were of the nature of memoranda could understand them, and finally adjust them. I wish to emphasize the fact that I was repeatedly urged to furnish the engineering surveyors with topographical map data as a guide in their special work.

The CHAIRMAN. Is Mr. Bodfish in town now?

Mr. JOHNSON. Yes, sir. This unfinished material, covering about 1,000 square miles on the plains of Colorado, the engineering surveyors, as I expected, could not interpret. Thereupon pending the final completion of the maps, they entered upon work in the mountains, where they had the benefit of the old Hayden survey maps, at least. To do this was comparatively easy, for in addition to the Hayden maps, this region afforded opportunities for several good sites, of which every one knew. In every great river basin, as well settled as that of the Arkansas, out of the great number of opportunities for storage and for conveyance of water, to be discovered only through systematic study of the grades of the ground over its entire surface, there naturally will be certain obviously good sites, or seemingly good sites, about which there will be general knowledge. To such spots Mr. Bodfish went and there ran his careful levels and made the accurate and necessarily expensive special surveys. Aside from such work as this he engaged in what Captain Dutton, in an earlier letter, of June the 10th, pressing me for maps, described as reconnaissance work. Captain Dutton said: "Mr. Bodfish's work during the present season can hardly be more than the reconnaissance work. Ultimately, of course, we must have the thoroughly completed map."

Over the mountainous area covered by the old Hayden survey we did revision work merely, adding only what would be necessary for republication on the larger scale proposed. Here, when my principal assistant, Mr. Bien, found himself carrying his general surveys over the region in which Mr. Bodfish was making precise local surveys, we were again met with calls for map data, and we again, of necessity, furnished the unadjusted data. This, though confessedly incomplete, was found a useful guide, and at other points in the same region similar data were afterwards furnished at intervals.

Mr. Bodfish was even here working at a disadvantage, and it was, and in my opinion, everywhere must be, only over such limited areas, where the problems are of simple character, that such work can be conducted with even limited success without that full knowledge of the entire area under examination, which only a topographic map can give—make it by what method you will, and call it by what name you will. Next summer, as Captain Dutton wrote me, they must have the thoroughly completed map, and by July they may have it—more than 20,000 square miles of it—an area nearly three times that of Massachusetts.

They have now, to be sure, the Land-Survey maps; but these maps do not show the topography, and even as horizontal plans, they are imperfect and misleading. It is the topography—the vertical departure from the ideal level surface, that is all-important. A map becomes topographical only when it shows this surface form; furthermore, it is now generally agreed that the most satisfactory method of representing topography is by means of contours, which have something of the graphic effect of shading, and at the same time convey information in regard to elevation and depression that is both definite and quantitative. It is a topographic map of this character that this survey is making.

The CHAIRMAN. The land-survey maps are of the plains regions?

Mr. JOHNSON. Yes, sir; and of the valley areas in the mountains also.

The CHAIRMAN. You had nothing to do with the topographic work of other divisions?

Mr. JOHNSON. No, sir. We did no work outside of the Arkansas River Basin. The rim of that basin on the north, west, and south, and eastward to the one hundredth meridian constituted the limits of our area. We have surveyed the greater portion of it, and much the more difficult portion. Within these limits I conducted the general survey, and within the same limits the engineers conducted here and there their special and unconnected surveys of high precision (by comparison with which the topographical work is approximate)—by widely different methods, at relatively great cost, and yet surveys merely, none the less. I deem it important to the general question, to which you ask me to confine myself, that it be understood that all of this work is of the nature of preliminary surveying. The several names for what are virtually one thing and directed to a common end are here, I think, more misleading than useful. In field work they serve in the division of labor.

The expensive trial-line work is conducted with a special object directly in view. The general and comprehensive survey, which achieves a topographic map as its result, aims only indirectly to convey this special information. For whatever purpose it may be made, to whatever purpose it may be applied, such a survey accomplishes nothing more nor less than what I have described as a topographic map. Whether by an irrigation survey, or by a geological survey, or by a railroad-lands survey, it answers to that definition—a map showing the form of the surface, as a rule by contours—and to each it is practically indispensable, as it directs attention, without waste of energy, to such special details as require minute investigation; and to each, as well, it affords a graphic base for the record of multitudinous additional facts in natural groupings.

The CHAIRMAN. Is it not possible for the engineers, in the mountains, to follow up the streams, and to make locations by observation, and with their instruments, without having the topography in advance?

Mr. JOHNSON. It is possible, especially in the mountains, and along the main stream lines; but even under such simple conditions the engineer may, here and there, fail to discover important facts. Expensive mistakes must inevitably, in my opinion, follow a course which appears, in view of the magnitude of the work contemplated, dangerously loose and unsystematic. And I am speaking of the trial-line method under favorable conditions. The best sites for storage will frequently lie to one side of the main streams, and to these the waters must be led; the great canals and the minor canals will run across the barren spaces between the main streams; and here also will be found the lands to be irrigated. Failure to carry examination over these interstream areas must occasionally result in wasteful work, and discreditable blunders. The topographic map shows all the possibilities and all the impossibilities.

The CHAIRMAN. Is there any difficulty in having an engineer pass along an ordinary stream and determine the possible and impossible sites with his instruments in a short time—in a few days, for instance?

Mr. JOHNSON. Yes, sir; to determine all the possible sites for a given stream basin; not simply the flat places along its immediate valley, but in the adjoining and higher valleys as well; to determine the lines—the best lines—of getting the water there, and away from there, on to lands in some less watered basin or unwatered table-land; to do these and

other complex things, and at the same time to be sure that no fact has been overlooked, would, without a topographic map, or its more expensive equivalent, be more than difficult—it would, in my opinion, be impossible.

The CHAIRMAN. If you were going to locate a reservoir would it not be necessary to run trial lines for that particular place?

Mr. JOHNSON. After the topographic map had been made?

The CHAIRMAN. Yes.

Mr. JOHNSON. After the topographic map had been made it would still be necessary to resurvey, by relatively precise and expensive methods, all actual sites chosen for reservoirs and canals, or provisionally chosen with a small margin of doubt. These areas over which resurveys would of necessity be made would, however, appear in the great breadth of country represented by the map as spots merely. But the map is the indispensable and unerring guide to these spots. It says: Here spend your money; it will be wasted elsewhere.

The CHAIRMAN. The engineer has his levels with him, and can easily make experiments and make his locations without spending much time with trial lines?

Mr. JOHNSON. The area of country that a man can cover in that way, at a fairly reliable distance from his base, is exceedingly small, although it may appear to him large when on the ground. I find that, in criticising and examining in the field the work of my assistants, map in hand and merely by eye, the area thus revised by me is insignificant as compared with the body of land surveyed. The arid lands are of great extent. Such rapid work as the engineer may do by his general oversight, the topographer does also at wonderfully small expense, and much better and more rapidly, because his work is part of a system.

The CHAIRMAN. Suppose we take a river that has a great many tributaries. Each tributary, whether you have a topographic map or not, must be examined to see if you can store its waters, and the engineer follows up the tributary to its source. Would he not necessarily be guided to the localities where there will be flat places, where he can make reservoirs?

Mr. JOHNSON. He would not, with the map, need to do all this work in the first place; and without the aid of maps, he would not be sure to discover all the complex possibilities and impossibilities of the case to which I have called attention. He could not be sure without much more work than you refer to.

The CHAIRMAN. Take a mountain stream. Do they carry the water out on a table-land from the heights where they store it, or do they let it run down the channel, as a usual thing, to be taken out where it opens out in a valley?

Mr. JOHNSON. It is not so much a question where the water shall be taken out, as where it shall be stored. In many cases they might do as you describe; but my point is that years afterwards it might, in some cases, be found that great blunders had been made, involving the expenditure of vast sums, and that these blunders might have been avoided by the early expenditure of a very small, relatively insignificant, sum.

In the Arkansas Valley we began work in the vicinity of Pueblo. There irrigation work is actively carried on. Local engineers—men practically familiar with irrigation problems—had run trial lines all over that country. There had been much talk of taking the Arkansas out at some point far above Pueblo, to supply a large ditch and irrigate the country along its course by tap-lines, but it appeared impracticable to do so.

Many thousands of dollars had been spent, however, upon trial lines for various purposes over this same region, and had not discovered what our maps revealed immediately. My assistant, Mr. Hays, after working for a week or more in that region, said to one of the prominent engineers of Pueblo, "Why do you not take out a ditch at this place, and run it across here, and here, and store your water on the top of this table-land?" It had not appeared before that such a route was practicable. Appearances were against it. The gentle grades of that country are frequently misleading as to their dip. Mr. Hays urged, "Our maps demonstrate that it can be done." He showed the maps, rough preliminary drawings, but they gave, after an expenditure of a few hundred dollars only, what the local engineers had in vain spent thousands for. The Teller Ditch Company, so-called, was at once organized. A special survey, costing several thousand dollars, verified the prediction of the maps. This carefully surveyed line does not in detail coincide with that furnished by Mr. Hays, but it does coincide with fair approximation. It was enough that he had given them the general line. Construction work on this great ditch, to be the largest in Colorado, has already begun.

The CHAIRMAN. Do you mean to say it would have cost many thousands of dollars to have gone above, where it was suggested the water might be taken out, and to have run a random level to ascertain the practicability of doing so?

Mr. JOHNSON. No, sir; I do not. It would have cost very much less than the sum actually spent, and spent to no purpose. It would have cost less, because Captain Dutton's assistants would have gone about the work in a more systematic manner; but perhaps even they would not have thought of the line at all without the map to point it out. I claim for the topographic survey that we are doing it for the whole country. The engineer accomplishes the same result, but only here and there, and even then in a roundabout and expensive way. As we have the whole country to cover our methods belong to a unified system. I have here [indicating] a finished map showing the area covered by the preliminary sketch referred to. Here appears the ditch line as finally surveyed, practically coinciding with the line of the original, and demonstrating in this particular case the usefulness of such topographic data.

Senator GORMAN. Do I understand you to say that it is absolutely necessary, in your judgment, that this topographic survey shall be made before the engineers go upon the ground to determine this question?

Mr. JOHNSON. I am convinced, after a year of work among a people to whom irrigation questions are of vital importance, that it is in the highest degree economical, even essential, that the topographic survey precede the elaboration of plans for extensive and systematic storage irrigation. I am convinced that the topographic survey is the most economical means for ascertaining the necessary facts.

Senator GORMAN. How much more economical? Take the Arkansas basin. What would be your estimate of the additional cost of obtaining this information through the engineers without a topographic map?

Mr. JOHNSON. In my opinion it would be several times more expensive.

Senator GORMAN. Then it follows, in your judgment, in view of economy and results, that the special surveys should be suspended until after the completion of your topographic work.

Mr. JOHNSON. For the engineer to undertake his special examinations within a given area, in advance of the completion of the topographic map of that area, can only lead, it seems to me, to confusion and waste of money.

Senator JONES. Will you please explain your method of work?

Mr. JOHNSON. It has been so modified away from the prevailing methods of the text books as to be practically new. It is, in the main, that of triangulation—at first with the transit, by trigonometrical methods, but eventually, and chiefly, with the plane table, by graphic methods. By this triangulation distances are determined indirectly, but more accurately than by direct measurement. Yet the work is initiated by a direct measurement—by the measurement of one line, the initial base line; and this initial base is measured with extraordinary care. One line, several miles in length, is thus determined, and from this line the triangulation scheme is expanded. The first triangle is obtained by measuring the angles from either end of the base to a third point previously marked. By means of the only known distance and the two known angles the two remaining sides of the triangle are found. This triangle is the unit of the system, hence the name triangulation. Such triangles are multiplied by computing additional sides, or distances between points, by measuring the angles only, and computing the distances. Such a system may be expanded over an area of 50,000 square miles perhaps, such as that of the Arkansas basin, and the final triangle with its computed distances may lie several hundred miles away from the initial base. The last computed distance it then becomes necessary to test by actual measurement, and the test of the last link is a test of the whole chain. This second measured line is called the verification base. I have indicated only the principles of procedure. The actual practice is somewhat more complex.

Upon the points located in this net of triangles the detailed map-work is based. The map is not made in one great sheet, but the total area is cut up into atlas-sheet areas, as in the case of the Arkansas basin, of about 1,000 square miles each. Speaking more accurately, the positions and boundaries of these atlas sheets are determined by the half-degree lines of latitude and longitude. Now, under the best conditions, upon each of these atlas-sheet areas, of nearly 1,000 square miles each, three of the precise locations of the primary triangulation should fall. The positions of these points must be furnished, to the map-maker proper, in terms of latitude and longitude, so that he can plot them accurately on his map sheet. This map sheet, mounted on a drawing board, and this again on a suitably constructed tripod, is then taken into the field and the map is made directly upon it, and upon similar, but smaller supplementary sheets. The drawing board, with its tripod of special construction, is called a plane table, and the method thereafter is, throughout, the plane-table method—a graphic method—the most direct and simple method for making a map, which is, itself, a graphic product.

The three points plotted upon the map sheet are termed its primary control. From these a secondary triangulation or control is spread directly upon the paper until many small triangles affording, perhaps, two hundred secondary locations, are determined within the area of the single primary triangle formed by the three primary points. This work is done by means of a telescope, with attachments similar to those of the transit, but mounted on a flat plate or broad ruler base, and resting directly upon the plane-table map sheet. Elevations are carried forward from point to point by means of vertical angles—a method of vertical triangulation.

So far, however, we have no visible map, merely control. The smaller, supplementary sheets, are now furnished to traverse men, as they are termed. The points of the secondary or graphic triangulation are

plotted upon these traverse sheets, as the points of the trigonometric triangulation were plotted upon the larger sheet, and at these numerous control points the traverse men start and close. The elevation above sea-level of each of these points is also written on the smaller plane-table sheet, at a fine pricked hole, representing the located point. The method of the traverse man, as the name implies, is that of traverse, or meander—the same in principle with that of the trial line, but far less precise, and astonishingly rapid. The precision of detail, such precision as may be required, is attained by means of the check points. By the trial-line method, also a map may be made, but at relatively great cost, with great nicety in detail, but with gross inaccuracy in general proportion. These check points furnish with accuracy, and at a minimum of cost, that which line surveying, however carefully executed, can not furnish at all—the skeleton plan. By this method of triangulation a degree of closeness, in the determination of horizontal position and of elevation, may be reached, beyond the possibilities of the map to express, on the scale adopted. In estimating the cost of such topographical maps, per square mile, that of the primary control, though executed with great care, will be hardly more than 1 per cent., that of the secondary control perhaps 20 per cent. The traverse man, as stated, starts his line from a known point, and runs to other known points, checking and adjusting backward his error. The distribution of control points is, or should be, such that the probable error, after such adjustment, will be inappreciable or unimportant on the scale of the map.

In running his lines the traverse man depends for distances upon automatically counted revolutions of a wheel of his vehicle, and upon a further graphic triangulation, which he carries down even into this detail; for directions he depends upon his compass, and also upon this rough triangulation; and for elevations—for the detail of the grades of the surface, he depends upon the aneroid barometer. All of these approximate means are directly dependent upon the control locations, and errors are not cumulative. By running his lines close together and locating by intersection—by his rude triangulation, intermediate points, and by getting heights at such intermediate points by rude levels across between his lines, he surveys area and makes a map. I have here on this map, or large progress diagram, the area of an atlas sheet of 1,000 square miles, exhibiting the primary locations, the secondary locations, and the lines followed by the traverse men. You here [indicating] see the whole method graphically displayed. I have ruled this area into squares, representing square miles, on the scale of one inch on the map to one mile on the ground. It will be seen by following these red lines, which stand for the meandered lines, how well they are distributed for the control of area, as we say, and also the curious influence of the topographic configuration of the country upon this distribution. Within this area the traverse men have meandered, covering by their intersections belts of country on either side, a total distance of more than 3,000 miles. The total area must be covered by these belts and no blanks left. No blanks can be left, because, the method being a graphic one, a blank will appear as such on the map.

Senator MOODY. What has been the total cost of this topographic survey within the Arkansas basin?

Mr. JOHNSON. The total expenditure to date, for topography, in the Arkansas Basin, since I began work in the fall of 1888, has been $57,000. We surveyed 22,000 square miles, and, when completed, the maps will have cost $3 per square mile. This statement includes the heavy expenditure for equipment. I had about fifty animals, and seven

or more separate camping parties. This expense for equipment, in this new field, will not have to be incurred again. Omitting this large item, the cost per square mile has been about $2.

Director POWELL. Let me add to Mr. Johnson's statement of topographic methods an explanation of the manner in which we get starting points for elevations. There is a plexus of railroads all over the United States. Lines now meander from the Atlantic to the Pacific coast, and from city to city of the interior, and these lines are connected at their termini, and they cross one another in various ways and at various places, forming altogether a net-work of roads. In their construction levels have been run, and by connecting their lines altogether we are able to discover discrepancies in these levels. The roads of the country have been very generous to us and have furnished us their profiles, so that we have in the Geological Survey nearly all the profiles of all the railroads in the United States. Whenever discrepancies between levels of the different roads are discovered we report them to the engineers of the roads, and the errors are soon detected. Having in this manner a vast system of level lines run all over the country, we have a basis from which the levels of the topographic survey can be reckoned.

Senator JONES. You select a height from which you desire to start a system of elevations, and then you run a level from the railroad to determine its elevation.

Director POWELL. Yes, sir; and check on other railroad levels from time to time.

Senator MOODY. Mr. Johnson, you are, I understand, the topographer for the Geological Survey?

Mr. JOHNSON. Not exactly; a topographer of the Geological Survey assigned to special duty on the Irrigation Survey for irrigation topography.

Senator MOODY. Is there any distinction between the expenditure for topography in the Geological Survey and for topography in the Irrigation Survey?

Mr. JOHNSON. I know little about that, sir.

Mr. THOMPSON. (Interposing.) The expenditures are kept entirely separate. Mr. Johnson's work was on the Irrigation Survey.

Senator MOODY. How do you keep the expenditures separate?

Mr. THOMPSON. The money allotted is drawn by requisitions on the Treasury, and the account kept separately.

Senator MOODY. How do you keep it separate?

Mr. THOMPSON. There was no geological work going on in that region.

Senator MOODY. Can you tell me where this topographic work was going on for purposes of irrigation?

Mr. THOMPSON. In Montana, Idaho, Colorado, California, Nevada, and New Mexico.

Senator MOODY. All for irrigation?

Mr. THOMPSON. Yes, sir.

Senator MOODY. In putting your work on topographic maps do you make any distinction between the irrigation topography and the general geological topography?

Mr. THOMPSON. In this case it was all for irrigation. There was no distinction, because it was all for one purpose, the Irrigation Survey. Had we been making it for geological purposes it would have been substantially the same.

Senator MOODY. What distinction do you make when you come to make maps? Do you have to go over the ground again for geological purposes?

Mr. THOMPSON. No, sir; the same topographical map answers for the geological survey.

Senator MOODY. Then the geological survey answers for the irrigation survey.

Mr. THOMPSON. Yes, sir. As the geological survey was previously conducted——

Senator MOODY (interposing). I mean as it is now in that country.

Mr. THOMPSON. I had charge of similar work of the geological survey before being assigned to this. The work was in principle precisely the same. It is simply an extension in methods of the geological survey topography.

Senator MOODY. That is, you add this specific detailed information as to elevations, etc., for irrigation purposes to your topographic surveys for geological purposes.

Senator JONES. Let me understand that. I understood Senator Moody to ask you, if, as a matter of fact, there is a geological survey for a given part of the country, this irrigation survey is made to supplement the geological survey.

Mr. THOMPSON. If the geological survey maps had been made in this region we would not have had to go over it again for the maps of the irrigation survey; but the geological maps had not been made.

Senator MOODY. Is it the intention to complete that whole country in one map eventually?

Mr. THOMPSON I can not speak as to what the intention is.

Senator MOODY. What I want to ascertain is this: Is it necessary, in your pursuit of geological information, for you to go over this ground again, after you have made this sort of topography?

Mr. THOMPSON. No, sir; not to make the map.

Senator MOODY. Now, can you put those divisions of the country together, where you have a map of one region on a scale of 1 inch to 4 miles and a map of another region, adjoining, on a scale of 1 inch to 2 miles?

Mr. THOMPSON. If we were to join these two maps, this map [indicating] would show the country more in detail. Every other one of the 100-feet curves represented on the large scale would exactly join with the 200-feet curves on the small scale, which covers 4 miles to the inch. They would join there. If the 4-mile map were photographed up so that it would be on a 2-mile scale, they would join.

Senator MOODY. Is it not sufficient, for engineering operations in irrigation, to take this geological survey map instead of making this irrigation topography?

Mr. THOMPSON. In my judgment, it would be sufficient.

Senator MOODY. You have this information, but you have to go on the ground and locate with more detail?

Mr. THOMPSON. Yes, sir. It is a mere matter of revision, quite rapidly done, because we take the map right into the field and draw the contour lines upon it.

Senator MOODY. Now, in your irrigation topography you do precisely the same thing in the first instance. That is the first work you do—what may be called the reconnoissance, the preliminary or observation work. You do precisely the same thing in both cases, for irrigation and geological topography.

Mr. THOMPSON. The same in method, but we obtain more refined determinations in relation to the streams.

Senator MOODY. It is important that we should understand what is essential in the way of appropriation for actual irrigation purposes and

what is essential for geological purposes, that is, for the geological observation and survey that is going on, and what I want to know is whether we can use in this irrigation work the topographic maps that you have already made or are ready to make.

Senator JONES. As I understand, they are already made.

Director POWELL. This whole discussion is proceeding on a mistaken notion on the part of Professor Thompson of the import of your question. May I explain it?

The CHAIRMAN. Certainly.

Director POWELL. We have been doing work for a number of years, making topographic maps in the arid region. The ones that we have been making——

Senator MOODY. Did you make any topographic maps of this region where Professor Thompson had charge?

Director POWELL. No, sir; this is new work. I wish to speak of the relation of one to the other. A topographic map must be made for the geological survey and one for the irrigation survey, but they are one and the same, not two maps. The same map serves both purposes. There are certain areas of country where we need it on a scale of 4 miles to the inch; other regions on a scale of 2 miles to the inch. In the regions we have surveyed heretofore we have gone farther into the mountains. There we have made the maps on a smaller scale, but sufficient for our work in geology and irrigation alike.

Senator MOODY. What is the difference in paying the expense of this sort of topography out of your geological survey appropriation?

Director POWELL. None at all, if Congress makes a sufficient appropriation. It makes no difference.

Senator JONES. If Congress makes a specific appropriation for a geological survey the director would be obliged to expend it for that, and if there was a specific appropriation for an irrigation survey he would have to expend it for that, but he can make a map for both.

Director POWELL. The cost of the map necessary for irrigation over the cost of the map necessary for the geological survey is a trivial thing. It is involved in the running of the gradients of the streams.

Senator MOODY. We have secured for actual irrigation purposes $89,000 out of the $250,000, it seems, and the expense has gone toward this topographic work.

Director POWELL. What I am trying to get at is——

Senator JONES. I should think that objection would lie to the whole amount. The engineering and hydrographic work are no more important to the irrigation survey than the topography. They are all a means of finding out what is essential to the location of reservoirs and dams. It seems to me if you object to one, you must object to the other.

Senator GORMAN. Take this survey you have made. What would be the difference in the cost to the Government between using your topographic map for geological purposes and the one which includes irrigation as well as topography?

Director POWELL. One map serves both purposes.

Senator GORMAN. What is the difference in the relative cost of producing those two maps?

Director POWELL. That which is necessary to be done for irrigation purposes, over and above what is necessary for geological purposes, would not exceed 1 per cent.

Senator GORMAN. It would not be more than 1 per cent?

Director POWELL. No, sir.

Senator REAGAN. All that would be necessary would be to narrow the contour lines?

Director POWELL. No, sir; that is not necessary. The only additional work is the running of the gradients of the streams with accuracy.

Senator GORMAN. So that in this arid country you think it would be wise to make the appropriations to include both?

Director POWELL. Yes, sir. I do not think we ought to do the work twice. By my method when it is done for one purpose it is done for all.

Senator GORMAN. I would like to ask you, in view of what Mr. Johnson has said, why is it, in pursuing this inquiry, if the geological survey was absolutely necessary to economy and results, that you put the engineering parties into the field prior to the completion of the topographic work?

Director POWELL. I have explained that to the committee heretofore, but I will explain it again. Four or five weeks ago I explained to the committee that in the Arkansas Valley I knew of some reservoir sites, so that it was not necessary to have a topographic survey to discover what was already known. I knew that Twin Lakes was a reservoir site, and I knew of others. I had been studying that country for twenty-two years. I was at Twin Lakes twenty-two years ago.

Senator JONES. You had a topographic map of that country in your head.

Director POWELL. Yes, sir; I knew certain sites, and I said to my engineers, "We will not wait a year for a topographic map, but take the sites we now know, and examine them while the topographic corps is discovering the remainder." So I sent a small engineering party to make plans of those reservoirs, the sites of which were already known or supposed to be known.

Senator GORMAN. Is that the case with every engineering party that you sent out?

Director POWELL. Yes, sir. When we sent out an engineering party we knew much of the special ground it was going on.

Senator MOODY. Then for irrigation purposes you could have saved this $57,000.

Director POWELL. No, sir. Only a few sites were known and many had yet to be discovered; the topographic work had to be done to discover them and to find out how much water could be furnished by the several catchment areas, and to discover canal sites, dam sites, etc.

The CHAIRMAN. This engineering work for the purposes of irrigation only needs to proceed as the settlement of that region requires it. It does not need to be done in a day, because the land can not all be occupied in a day. As I understand you, the engineering party proceeds in advance of the topographers where reservoir sites are already known. Now, what is the difficulty in allowing the topographic survey to go on, and permitting the engineering to proceed independently of it? Must the engineering survey, particularly in localities where they want the water immediately, be retarded by waiting for the topographic survey, or may the engineers go on, using what topography you already have, and survey the known basins, make estimates, and let the people use them?

Director POWELL. Let me explain. There are two things that must be determined before the ultimate plans for construction of works can be approved and published to the people. We have got to know what water is to be controlled. If we make an error in that the whole thing is disastrous. If we plan a reservoir site and have not the data before us so

as to know how much water has to be controlled for that reservoir site, the reservoir may be constructed, and the first great storm that comes along will destroy it, sweep it out. We must know what that drainage area is, what the supply of water is. That can not be determined by any other method than the one which I have adopted in less than ten to twenty years. I have done it by topographic methods in part. I have explained to the committee how I determined that. It is impossible to do it in any other way as quickly or as cheaply. Second, if we do not make a topographic map, we can not make reports until the end of a series of years after the streams have been gauged. Then, by taking the other method we make it cost five times as much, as I have already told the committee.

The CHAIRMAN. Do you mean to say that nothing can be done until the topography is complete in each?

Director POWELL. Let me illustrate. We can not put on the roof of a house until the walls are built. We can not erect the walls until the foundation is laid, but while we are laying the foundation we can haul the bricks and cut the shingles. For each particular basin or reservoir we must have the complete topography before we can report upon it. Suppose there is a little stream which will furnish 10,000 acre-feet of water in a year. I must know the drainage basin of that stream before I can plan that reservoir and know that there is 10,000 acre-feet of water to be controlled.

The CHAIRMAN. That is the work of your engineer, is it not?

Director POWELL. No, sir. No railroad manager would put the freight system, the passenger system, the ticket system all under one man. A house-builder does not employ the same man as a mason, a carpenter, and a plumber. My men are all engineers, but I have classified them, putting one class of work into one man's hands, and another class of work into another man's hands, so as to get the best work from each.

The CHAIRMAN. Then, I understand the work you have done in those localities where the topography has not preceded will be useless?

Director POWELL. No, sir. I shall have the topography ready for those districts before the plans are completed and the reports made. In two or three months the topography will be ready, and we can then tell what water the works will have to control by using the gauging of typical streams. The final report on the reservoirs of a stream can not be made until they have the topography. The engineers can not make their recommendations until they have. The work done in splitting the shingles for a roof is not lost, though it be done while the workmen are laying the foundations.

Senator GORMAN. Was the destruction of the dam in Arizona the other day caused by a disregard or lack of knowledge of these things?

Director POWELL. Yes, sir; the same as at Johnstown. They had miscalculated the amount of water they had to control, and when the storm came the dam would not hold the water.

The CHAIRMAN. Do you not think it was because there was not a sufficient waste-weir?

Director POWELL. My idea is that the dam at Johnstown was a good dam.

The CHAIRMAN. Had it a waste-weir?

Director POWELL. It had one but it was not large enough, for they had improperly computed the amount of water which had to be controlled.

The CHAIRMAN. Is it not easy to make an ample allowance?

Director POWELL. Yes, sir; if you know what that ample allowance should be, but suppose you do not know.

The CHAIRMAN. In torrential streams it would seem to be best to leave as much waste-way as before the dam was constructed.

Director POWELL. There is something more on that point. There is no use of building a dam to control 50,000 acre-feet of water if the basin is not going to supply it. I want to know how much water is going to come down, and the way to get that hydrographic information is by using the topographic survey. There is no other way of doing that except at great expense. Every gentleman who has spoken on that point here has said it would cost from four to ten times as much to do it by other methods than that adopted by me. My own judgment is six times.

The CHAIRMAN. In gauging streams you gauge the actual amount of flow?

Director POWELL. Yes, sir.

The CHAIRMAN. You take the gauge of one stream and use that as a basis for other streams in the same locality?

Director POWELL. Yes, sir.

The CHAIRMAN. You do not use any topography in gauging streams?

Director POWELL. No, sir.

The CHAIRMAN. And the gauging of streams under any system would be expensive.

Director POWELL. If I want to know how much water will run off of twenty-five roofs, I find how much runs from one roof, and then multiply——

The CHAIRMAN. Your explanation of that was very good, and I appreciate the advantage of that method. Would not the experience of people living on a stream indicate——

Director POWELL. It is a very dangerous thing to depend upon the experience of people for the data necessary to plan engineering works. Ignorant guessing will not do.

The CHAIRMAN. You can not rely upon it; but you can see the marks from floods, and gain some information from the experience of the people who live on the stream. As I remarked yesterday, the storms in that country have had no parallel since 1861–'62, twenty-nine years ago.

Director POWELL. We are very fortunate in having a wet and a dry year together, and all over that country I have taken advantage of that, and have been gauging the typical streams. Something was said the other day by Professor Thompson about the maps made by other engineers in California and I have brought the maps of California with me.

Senator GORMAN. I would like to have, for my own information, a little more light on the question the topographer in charge of the Arkansas Basin brought up, as to the administration of office details. He states distinctly that in that case, where the engineers were put into the field to locate the reservoirs and so on, their work was retarded, and its expense greatly added to, because the topographic survey had not been made. Now I understand you to say that you had general knowledge of that particular locality. I would like to have further information about it, and I will ask you whether it is not an absolute necessity to stop the engineering surveys until the topographic map is made.

Director POWELL. The actual surveys of the reservoir sites themselves should follow the topography. Last year they could have done

so, for I had topography in other districts; but they did not go into the districts in which I had topography already collected for a very potent reason.

Senator MOODY. What is that reason?

Director POWELL. I am proceeding to give it. The people of the Arkansas Valley were in conflict about water rights. It is a country that is densely settled, and they were suffering for water, and I thought it was wise to go and give speedy relief. So I went to the Arkansas Valley. The legislature of Nevada had made an appropriation to construct irrigation works, and they wanted to know where to put them, and I went there to solve the problem as soon as possible. So, in all the work I did, I went into densely populated districts, where the problem was pending over the people, believing the people were anxious for the information at once; and I attempted to get that information in the best way.

Senator GORMAN. Then it was the local pressure that made you pursue a course which was not economical?

Director POWELL. Yes, sir; not the solicitation of individuals, but the pressure that came from a knowledge of urgent wants of the people. But these urgent wants were represented by governors, by members of legislatures, by boards of trade, and leading men of the country. There are certain districts of country in the arid region already highly developed by settlement, and where the water supply of the smaller streams is already used during the season of irrigation. In these districts the people desire to know how to control the greater streams, and especially how to store the surplus water, which is very great, and I went into those districts where the problems were pressing for immediate solution. In those districts I already knew some of the facts, but not all, and I acted upon the basis of facts known. I knew certain reservoir basins, and I said, "We will go on and get the information about these basins and supplement our work by the topographic information which we are already collecting," for the topographic survey preceded the engineering survey by about seven months.

For a year or two past there has been excessive drought in the arid region and large areas of crops have perished by reason of them. In those districts the people wanted early information and I believed it was wise to give them that information and adjusted the work to the conditions existing. In entering upon the work I believed that some loss would be entailed, but that it would be entirely insignificant in comparison with the good that would be done. One of the places which I entered upon was the valley of the Rio Grande above El Paso, because the people in the valley had had their agriculture destroyed. The values involved amounted to millions, and I took up the problem to see what could be done to save those people, and have discovered a practical solution, and it has already been presented to this committee and to a committee of the House, and that conclusion has received the approval of both committees and they have introduced bills in both Houses to apply the remedy proposed. I might have proceeded by the other method to solve the problem in the same manner with a saving of $1,000 or $1,200, but a speedy solution of the problem seemed desirable and I shouldered the responsibility.

Senator GORMAN. Then, I understand that in the administration of this trust, if appropriations are made hereafter, you will complete the topographic maps before putting the engineers at work.

Director POWELL. Yes, sir. I shall have enough topography this year to employ my engineers for the next year.

Senator JONES. Has there been any waste of money in the location of such reservoirs as you have located?

Director POWELL. If we had had our topographic survey finished we would have had less lines to run and would have saved something thereby.

Senator GORMAN. What was the difference in the Arkansas Basin between the cost of making the survey in the way you made it and making it after you had the topography?

Director POWELL. It cost $1,500 or $2,000 more than it would have cost if done the other way.

Senator GORMAN. What was the total cost of the engineering party in that basin?

Director POWELL. I think about $19,500.

The CHAIRMAN. Has the work been completed?

Director POWELL. Only on certain reservoirs. The great body of the engineering has yet to be done, and the engineers will proceed with it with the maps in their hands, and do it right, and reach results that can be given to the people with confidence because all the facts will be discovered by the topographic survey.

The CHAIRMAN. I mean the topographic survey of the Arkansas Valley.

Director POWELL. It has been completed nearly to the one hundredth meridian.

Mr. THOMPSON. It is completed to 101.30.

The CHAIRMAN. What proportion of the Arkansas Valley has been completed?

Mr. THOMPSON. I am speaking hastily, but I should say that of the Arkansas Valley out to the State line, about four-fifths has been completed.

Director POWELL. Now, Mr. Chairman, you have seen that we are making topographic maps for the irrigation survey, and the reasons for making them have been given. It has also been explained that the same maps are to be used in the geological survey. The maps are made once, and only once, and serve both purposes. In other regions we are making the same kind of maps on the same scale for geologic purposes and the geological survey is going on in some regions where irrigation is necessary and the maps which are made for the geological survey serve both purposes. The irrigation-survey maps are all that is necessary for geology as well as irrigation; the geological-survey maps are all that is necessary for the geological survey and the irrigation survey. In another region of the plains we are making topographic maps for the geological survey, and I have brought them with me. You will see, as I spread them before you, that they are made on the same plan as the others and on the same scale, and in like manner reveal the storage basins. Here in Kansas is one of the finest storage basins we have ever discovered on the plains, and it has been discovered by the topographers of the geological survey. The topographic work had to be done for the geological survey, and in making these discoveries they added substantially nothing to the cost of the work. I wish, Mr. Chairman, to make it clear that the topographic survey is done but once, and then done for both purposes. I have explained this matter to the appropriations committee and you will find it in the report of that committee which I hold in my hand.

The CHAIRMAN. Was that map made previous to the irrigation survey?

Director POWELL. It was made last summer, at the same time that the irrigation topography was in progress in another region.

Senator MOODY. You are making maps by the irrigation survey which can be used in the Geological Survey?

Director POWELL. Yes, sir. All the maps made by the irrigation survey will serve for the Geological Survey, and all maps made for the Geological Survey will serve for the irrigation survey. [Refers to map.] You see here is the Arkansas River. Here is a little basin, 5 miles from the Arkansas River, at about the ninety-ninth meridian. This is in the subhumid region. We are pushing the topography for the Geological Survey in the subhumid region and pushing the irrigation survey in the region to the west.

Senator MOODY. [Indicating on map.] Is the water taken out there?

Director POWELL. Yes, sir; it is taken out there. We can create a lake there [points], and there is low land lying along there to which the water can be conducted.

The CHAIRMAN. Is there anything else you wish particularly to present?

Director POWELL. I have not yet had twenty minutes in which to make a clear statement of the case. If I could have twenty minutes I would like very much to have it. I have been so frequently interrupted that I have drifted everywhere.

Senator MOODY. Still you have given us much information, and it is always a good thing for us to suggest questions, because then you know what is running in our minds.

The CHAIRMAN. Could you condense what you have to say and send it in writing?

Director POWELL. I can.

The CHAIRMAN. Do that, and bring it in.

Director POWELL. I will attach it to my statement. If the committee want opinions about this matter I should like to have the Superintendent of the Coast Survey brought here. I want to say to you that I had selected the present Superintendent of the Coast Survey to take charge of this work. He had the matter under consideration when the President offered him the position he now occupies. He is one of the best hydrographers in America.

The CHAIRMAN. What is his name?

Director POWELL. Mendenhall. He is familiar with the problem, and has discussed it with me.

The CHAIRMAN. I think we will call him. I would like to hear what he has to say.

Director POWELL. If you will address him a letter, asking him whether my method, with which he is familiar, is the most economic, most thorough, and most speedy, I think he would answer.

Senator MOODY. Is there any necessity for topography for the surveys you make out on the plains?

Director POWELL. Whenever I am allowed I want to present to you the question of what kind of a survey is needed on the plains; it needs a slightly different survey from that of the mountain region.

Senator MOODY. Can you state, in a general way, whether there is any necessity for the topographic survey?

Director POWELL. Yes, sir; it is chiefly topography on the plains. Professor Thompson told you that the British Government has made a topographic survey in India. That government has covered much of India with a topographic survey, and I can bring you many volumes of the reports of that survey. Everywhere in the civilized world, with-

out any exception, they make topography the basis of an irrigation survey—in Italy, in Spain, in France, the French in Algeria, the Russians in their arid regions, and the British Government in India and the French and English engineers in Egypt, and I have specimens of the maps which they made with me if you wish to see them.

The CHAIRMAN. Suppose the engineers took the same instruments that you use, what would be the difficulty of their making the topographic survey that would be necessary for their work in the same manner that you make it preliminarily, but on a smaller scale, to ascertain where to locate their ditches, and all that?

Director POWELL. None at all if on the same scale; if on a smaller scale it would not serve the purpose. But I would not take the man who is to stand by the river gauging the water and break up his work by sending him away to discover reservoir sites or canal sites or the area and declivity of drainage basins. He has all the work that he can do on the rivers in measuring their flow. I would not take the man who is to plan the dam and have him measure a river 20 or 30 miles away, and hunt a canal site perhaps 20 or 30 miles away in another direction. I would divide the work among skilled men, so that each one should do his part in the most economic and thorough manner. All the men are engineers, all doing work of the irrigation survey, but the work is divided among them on the economic principle well known as the division of labor. On a railroad one man is not ticket agent, freight agent, engineer, brakeman, and surveyor, but the work is divided among the men, and each takes his proper part. So in the irrigation survey, the work is divided among the men and each takes his proper part, one to do topographic work, one to do hydrographic work, and one constructive work.

Mr. Chairman, you have already received statements from myself and my assistants of the amount of money allotted at the beginning of the season to the topographic work, the hydrographic work, and the engineering work, and you have learned that a sum of money was reserved for subsequent contingent expenses. That reserve fund has been chiefly used in two ways: the engineering and hydrographic work has been strengthened in some places, and a small amount has been used in that manner; but the principal part of the reserve fund has been used in making segregations of land as required by the statute. Everywhere throughout the country it has been found that the people were anxious that these segregations should be made at the earliest possible date.

The statute reserves them from the 2d of October, 1888, the date of the signing of the act, even though the selections are not made until some time later. Whenever they are made the date of reservation is the 2d of October, 1888, and there were two reasons why the people wanted these segregations made rapidly, first, that they might know what lands were withdrawn from occupation and sale under the desert land act, timber land act, and pre-emption act, and which could be settled only under the homestead act; second, they are exceedingly anxious that reservoir sites and canal sites should be withdrawn from sale that they might not fall into the hands of individuals for speculative purposes, and a great pressure was brought upon the Director of the Survey to make these segregations speedily, and the work was carried on with all the vigor possible. A great number of reservoir sites, such as mountain lakes, etc., already known, were re-examined through the aid of the Land Office plats and from the general geographic information in the possession of the Survey; and such sites were cer-

tified to the Land Office as being reserved under the provisions of the statute. The general information in the possession of the Survey also indicated that certain great tracts of land should be reserved under the statute. A reconnaissance of such lands has been made, the Land Office plats examined, and 30,000,000 acres of land have been selected for final examination in the Land Office, so as to exlude all lands on which legal filings have been made. In one case, on Bear River, in Idaho and Utah, the people were in conflict, and the governors and people petitioned the Secretary of the Interior asking that lands in that region should be protected from occupation at the earliest date as important reservoir and canal sites were being occupied, and the Secretary of the Interior, while I was in the field, telegraphed me a peremptory order to send officers to that region and make the necessary segregations, and it was done.

For more than twenty years I have been conducting explorations and surveys in the arid lands. During the first year of my work in that region my attention was directed to the arid land problem, and from that day to this it has been my chief study. My field of study has been threefold: First, I have studied the lands themselves and the waters which are to supply them, and the forest areas on which they are dependent. Then I have studied carefully the practice of irrigation in the United States, and much of it has grown up under my eye until 8,000,000 acres of land are now under canals in that region. Then I have provided myself with the literature relating to irrigation, especially the engineering literature. From all of these sources, and aided by counsel and advice from my assistants who are able men, I have gradually developed a system of survey of the arid lands. More than fifteen years ago I commenced the gauging of streams. More than fifteen years ago I commenced the selection of irrigable lands tentatively, and thousands of people—scores of thousands—have settled on lands selected by myself and under my advice, given through the agency of maps and reports.

The conclusions which I have reached are not hasty, for I have given to the subject the best thought and energy of my life. In the solution of these problems two men have been most intimately associated with me and they have been considering them to a greater or less extent for many years. I refer to Mr. Gilbert and Mr. Thompson. We have sometimes disagreed about practical methods, but ultimately we have arrived at substantially the same conclusions. And the plan which I have submitted to the committee and which I previously submitted to the Congress is the outcome of all that study. The theory was to make a practical survey at the smallest expense which would give the greatest amount of information to the Congress and to the people actually engaged in irrigation, and to do the work not in the interest of particular individuals or of corporations, but for all of the people; so that if the farmers were to control the waters for themselves they would know how to do it in a thoroughly economic manner, and if they were to engage corporations to do the work for them they would have the necessary information to make their contracts with intelligence.

I have witnessed the wasteful expenditure of much labor and money aggregating millions of dollars. I have witnessed the granting of rights to companies to furnish water that were improvident and I have witnessed the reaction from these unwise contracts expressed in conflict with the water companies and expressed in unfriendly legislation and local regulation by which improvident rights once granted were destroyed. It has been in view of all these facts that the establishment

of water rights where they were improvident and wasteful, the growth of the vast system of conflict from water rights which now exist, the impairment of the catchment areas of water by the destruction of forests, and the many other problems which I have already presented to the committee, that the legal, industrial, and engineering problems have all been considered, and I have for years been gathering all these facts and from time to time have been presenting them to the Congress. And the survey which I have gradually developed has been the chief agency for the accumulation of facts for the people, and as finally organized, was intended to assemble them completely and thoroughly in such a manner as to be of the greatest utility to the farmers themselves and to be of the greatest value to the States and to the General Government in the regulation and establishment of rights under this new industry.

It has seemed to me that by far the most important thing to be done in the interest of the people was to make a topographic map on which would be assembled in a graphic manner the principal tracts to be considered. I have, therefore, in the management of the early explorations and surveys, and later in the conduct of the geological survey, thoroughly represented the purpose and importance of the topographic map, and the subject has been examined by a joint committee of the two Houses and met with its approval. It has also been considered from time to time by the appropriation committees and moneys have been granted for its construction. When a more speedy and special survey was demanded and the statutes required that the lands and sites should be segregated and the works planned and the cost thereof estimated, I stated that the basis of the work would be a topographic map; that the map which we were making in the geological survey for its purposes would serve the purpose of the irrigation survey as ordered by Congress, but that to wait for these maps much time would be consumed; that as the work was then in progress it would take about thirty years to complete it, and that if it were desirable to prosecute the irrigation survey speedily it would be necessary to do the topographic work for the irrigation survey, and that the maps then constructed would serve the purposes of the geological survey; that topographic work must be done for each and both purposes, and if done for one would be done for both.

With this understanding the appropriations for the irrigation survey were made in terms requiring the preparation of the maps used—in the same terms that required the preparation of the map for the geological survey. The law, therefore, authorized the survey on the plan which I had recommended to the Congress and it has been faithfully pursued according to that plan. I represented, before the appropriation was made, that the map was necessary and the appropriation was made in terms authorizing its preparation. The question now arises, Was that plan wise? Is it the most accurate, the most economic, and will it give results to the people in the shortest time? My views on this matter have already been presented in part, but in a desultory manner from the fact that they appear in interlocutory form and often complete answers were not possible. I therefore desire to make a summary statement of the necessity for a topographic survey as the basis of an irrigation survey.

Under the survey I have to discover diverting dam sites, reservoir sites, irrigable lands, and canal sites from streams to reservoirs and from reservoirs to lands. All these are called for in the act. Some method of discovery, then, must be adopted. To guess at them by riding over

the country and then testing the guesses by trial lines is a very expensive method. It costs on an average $25 per mile to run a trial line on the ground. Altogether hundreds of thousands, perhaps more than a million of miles of trial lines would have to be run if this method were to be adopted, and the average expense of running a trial line, as shown by the experience of railroad companies in this country, is about $25 per mile. But I had already demonstrated that a cheaper method could be used. I had superintended the conduct of topographic surveys for several hundred thousand square miles and found that railroad engineers could use those topographic maps and save the expense of trial-lines. They could take a topographic map and select a line and survey that one alone for construction purposes, and this is now the practice of railroad engineers everywhere throughout the country where our maps are made.

Let me illustrate the economy of this method by a single instance: The Canadian Pacific Railroad ran trial lines which cost $3,000,000, and then built the road along a route which was not the best, and then changed the route over part of its course; and it is now discovered that the best route was still not found. Had a topographic map of the country, 200 miles in width from the eastern terminus to the western terminus, been made it would have cost much less money and the best line would have been revealed and a great saving would have accrued, and the map thus constructed would have served the purpose of all the tributary lines within the district and the purposes of a geological survey and everything else for which topographic maps are needed.

I have stated to the committee, and have made the statement after a careful consideration and years of study of the special problem, that the trial-line system for the discovery of lands and sites would cost three times as much as a topographic map system and when completed it would be less satisfactory. But if the topographic system were adopted it would not only be cheaper and more satisfactory for the purpose, but it would also serve the purpose of the geological survey and all other purposes for which topographic maps are used.

But the use of the topographic survey does not end here. There is yet another use of the topographic branch of the work equally important with the one already given and which would require it to be done were there no other reason for it. I refer to its use in the hydrographic survey. The arid region is naturally divided into many thousand distinct drainage areas, each one of which must be considered separately in planning irrigation works, as each one is a catchment area for the water which is to be controlled and used in irrigation. That the waters in each basin must be measured in some manner is manifest for the following reasons: First, if works are to be planned the amount of water to be controlled by the works must be known in each case. The dams to divert water should not be too great, nor too small; if too great an unnecessary expense is incurred, if too small the entire catch may not be secured. For the planning of dams also it is necessary to determine the volume of the maximum flood. All this requires a knowledge of the mean annual volume, the minimum annual volume, and the maximum annual volume, and the maximum flood volume. Again, if canals are planned they should be neither too small nor too large; if too small they can not perform the service, if too great they are made too expensive. Again, the gradients of the canals must be determined, and this depends upon the amount of water which they are to carry. If the volume is small the gradient must be large, if the volume is large the gradient must be comparatively small. Then the reservoirs are to be planned.

For this it is necessary to determine the amount of water which can be stored. It would be unwise to plan reservoirs unnecessarily large for the service, or so small that they would not perform the service. How, then, shall these waters be measured? Now, experience and long observation make it manifest that the gauging with meters and nilometers of the waters of each of the many thousand districts could be done only at a great expense.

But a careful investigation of the subject had already revealed another method, and when its cost was computed it was believed by myself to be about one-sixth of the cost of direct gauging. This method has already been fully explained to the committee. It is proposed to use the facts gathered in the topographic survey necessary for the other purposes, and to gauge a few typical streams with great accuracy and to derive from these factors and the general rain-fall tables in differing latitudes, longitudes, and altitudes a system of formulæ by which the water supply can be computed for each district. Thus it is proposed to solve the problems in part by experimental demonstration and in part by computation. I believe that by this method hydrometric results can be obtained superior to the results by direct gauging, and it can be done for a very much smaller amount, making a saving equal to twice the cost of the topographic map. It is thus that the topographic method of doing the work as compared with the trial line and direct gauging method will cost only about one-fifth of the amount which those methods would cost. If, therefore, it is considered that it is the most accurate and the most economic method, it remains to be shown that it is the most expeditious. This will appear from a consideration of the following conditions: A number of typical streams are gauged, the maximum rain-fall of any special stream may not be found without taking the observations for a long series of years, but of a large number of streams widely distributed throughout the country. Maximum and minimum volumes will be repeated now here, now there, now elsewhere, from time to time. We thus are able to get this maximum and minimum in a few places in a comparatively short time, and by the use of the method which we have adopted of measuring catchment areas and their declivities we can easily determine the general extreme conditions in each case without waiting for the long period of time to elapse. It is thus clear that results can be obtained in a much shorter time by the method adopted. It was therefore believed to be more accurate, more economic, and more expeditious.

It must, then, be remembered that the topographic work must be done anyhow for the geologic survey. That question has already been examined at great length by Congress and approved, and the law directs it. Whatever is done for the irrigation survey is thereby saved for the geologic survey. But it seemed to Congress that the irrigation survey should be pushed forward more rapidly than the geologic survey, and therefore the expense of the map is charged to the irrigation survey and paid for out of the appropriations made for that work, except in those regions where the geologic survey is in progress: there the maps constructed are used for the irrigation survey.

There is yet one other question in this connection which has been raised in the committee and which deserves complete answer. It is this: Would it not be possible to do a little work in each district from year to year, just enough to meet temporary wants, but to supply those wants fully? Of the thousands of districts which I have mentioned, there is no one which is not already settled, there is no one which does not already require the information which this survey will give. It is

not possible to do a part of the work in any one district and leave the whole unfinished and properly utilize that work. The entire district must be understood, surveyed, all the facts obtained, before any proper plan can be presented. Each such district must be completed before results can be reached which will be of value to the people and serve their needs. But more, it is sometimes the case that two, three, or more adjacent districts which lie in one great river system are interdependent; that is, they are so related that the problems in one can not be solved without at the same time solving the problems of the others. There will, therefore, be many cases where several districts, each having a distinct system of works, will have to be completed together. As the work of the whole arid region can not in all probability be done all at one time—because it can not be hoped that appropriations will be made for it in that manner, and if made it would be difficult to find the trained necessary officers and difficult to administer—there remains only the policy which has already been inaugurated, of selecting those districts where the problems are most pressing for immediate solution and of taking them in their order according to the best judgment of the officer who has charge of the work and administers the trust.

In conclusion, Mr. Chairman, I crave permission to earnestly urge the importance of doing this irrigation survey work in the most thorough manner. The extent of the area to be redeemed is involved in the question. If the work is well and properly done the greatest area can be brought under agriculture; if carelessly and badly done a much smaller area of agriculture will ultimately be developed. The relative cost of the construction of these works is also involved in good or bad work. If the work is badly done it may easily cost two or more times what it would if properly planned. This means ultimately differences of many hundreds of millions of dollars in all; and there is yet another consideration: All the waters of 1,500,000 square miles are to be used in irrigation; all the rain that falls from the heavens above those lands; all the waters that run in the brooks, creeks, and rivers. These waters are enormous, almost inconceivable powers, and they are to be controlled. It is possible to store these powers so that they will forever be a menace to the people whose agriculture will depend upon them. India, in which the waters have been stored for many centuries, is covered with breached reservoirs; and the problem of making these reservoirs safe for the people is considered the most important problem presented to the British engineers in India. That same problem is committed to the survey under my charge, and I think I have some realization of its magnitude. The officers associated with me in the work feel like responsibilities, and I must beg of you not to diminish that responsibility by prescribing methods of procedure in the work which must necessarily result in the preparation of plans with insufficient data, and in leading the people who construct the works astray, and submitting their property—their fields and homes—to imminent destruction and putting them in peril of their lives.

Mr. Chairman, for the long and patient hearing which you have given me I can only express most profound thanks.

NINTH DAY'S SESSION.

WASHINGTON, D. C., *March* 28, 1890.

The committee met at 10.30 o'clock a. m. Present, Mr. Stewart (chairman), Mr. Plumb, Mr. Moody, Mr. Jones, and Mr. Reagan.

STATEMENT OF SUMNER H. BODFISH, DIVISION CIVIL ENGINEER, U. S. IRRIGATION SURVEY.

The CHAIRMAN. What is your occupation, Mr. Bodfish?

Mr. BODFISH. I am an engineer in the Geological Survey, engaged in the irrigation division.

The CHAIRMAN. Were you engaged during last year in the irrigation work?

Mr. BODFISH. Yes, sir; I was engineer of the Arkansas division.

The CHAIRMAN. Will you state what use you were able to make of the topographic survey in the surveys which you made in the Arkansas division last year, and also state what necessity there was for such a survey in connection with your survey?

Mr. BODFISH. I have had no maps of the topographic survey in condition to use yet. The party has not yet finished its maps, as I understand.

The CHAIRMAN. Are topographic maps necessary for your engineering work in surveying for irrigation?

Mr. BODFISH. They are not absolutely necessary. If I had good topographic maps they would be very useful.

The CHAIRMAN. Can the engineering survey be carried on in advance of the topographic survey? In other words, can an engineering party do what topographic work is necessary for the purposes of irrigation?

Mr. BODFISH. I think it can. I think the topography should be under the immediate direction of the engineer, and such limited topography as——

The CHAIRMAN. What topographic work is necessary for irrigation purposes? Explain briefly how you carry on your engineering operations, to what extent you go into topography, and what use you make of it.

Mr. BODFISH. The irrigation problem, as I understand it, is simply stated: The first step is the discovery of a location for storage; second, the amount of water that you can store at that locality; third, the cost of storing that water, building reservoirs, etc., and fourth, the means of distributing the water over the country below and the cost of distributing it. In determining the location of a reservoir, if good topographic maps were in existence, they could be utilized, first, in a negative way, by keeping one from looking for a reservoir where there is great improbability of finding it; but as most of the reservoirs must be found on the streams and not off of them, it is better, in my opinion, for the engineer to search all streams, because unless a topographic map is made with great detail it is not possible to delineate everything in that map that might be utilized as a reservoir; this would be true, especially of a small one. The engineer himself should search every stream for the reservoirs, and having ascertained where they are, then make the necessary surveys for determining the amount of water that can be stored, and for estimating the cost of construction. Then he has to determine the amount of water that can be obtained there. If he knows

the rain-fall, the topographic map would be of some assistance to him; but from the map alone it is impossible to positively determine the run-off; the true way to determine the run-off would be to measure it at the point where the reservoir is to be located.

The CHAIRMAN. Must you necessarily go into detailed measurements at all places you build reservoirs, in order to ascertain the run-off? Is it necessary to obtain the details with that degree of accuracy?

Mr. BODFISH. No, sir; because the necessities of the reservoir site would not require it. He can judge from the appearance of the stream at the time he is visiting it, by the high water marks, or by talking with the inhabitants, or by comparison of the drainage areas above that reservoir site that he finds on maps, whether it is possible to build that reservoir. If it is a doubtful case, whether he shall build a great or small dam, it is a question he must make a careful examination to determine.

The CHAIRMAN. With regard to the construction of reservoirs on streams that are violent and torrential in flood times, what circumstances does the engineer take into consideration to determine what kind of a dam it is safe to build?

Mr. BODFISH. In almost all of those streams that are torrential there are high-water marks, because the torrential currents are so swift that they leave a mark; so he can determine whether it is a stream of that character.

The CHAIRMAN. Can he, from the declivities of the surrounding hills, without actual measurement, approximate the rapidity with which water will be forced against the dam in flood time?

Mr. BODFISH. I do not think he can.

The CHAIRMAN. He can not do that?

Mr. BODFISH. Not very accurately.

The CHAIRMAN. Then it is not ordinarily safe to build dams in these large torrential streams?

Mr. BODFISH. No, sir.

The CHAIRMAN. When you go into a stream like the Arkansas to build a dam high up, where it is torrential in flood time, how do you avoid the danger, and when you do build one, what precautions do you take?

Mr. BODFISH. If you do build one, the precaution would be to make it an overfall dam. The building of the dam would depend on the amount of water it would have to carry. If the stream is a rapid-falling stream, as is usually the case in those regions, the chances are very few of finding a good reservoir site; but you might find a gorge with a comparatively flat basin above, where you could store the water at a sufficiently low cost to warrant the construction of a high overfall dam.

The CHAIRMAN. Is it not sometimes possible to build dams in such places and turn the water over the rocks and give it as large a waterway as it originally had?

Mr. BODFISH. Sometimes; but I should say it is rarely possible.

The CHAIRMAN. In that country will not most of the dams necessarily be built out of the main stream?

Mr. BODFISH. In the Arkansas Valley?

The CHAIRMAN. Yes.

Mr. BODFISH. As far as I have become familiar with the Arkansas drainage basin, the reservoir sites are found on the streams.

The CHAIRMAN. Are there lakes on the streams which indicate reservoir sites?

Mr. BODFISH. Most of those I have found on the Upper Arkansas

have been caused by glacial action. They have been caused by the terminal moraines across the original drainage lines. They have been natural basins in the past. Farther down the stream there are a few small ones that have been made by the washings in from side gorges into the larger cañon, making banks between which you might build. Those are dangerous localities to build in, however; the foundations are precarious, and the large cañon, as a general rule, falls rapidly.

The CHAIRMAN. In utilizing these rivers, which class of reservoirs do you recommend the construction of first?

Mr. BODFISH. Those built on the streams.

The CHAIRMAN. They are much more expensive, are they not?

Mr. BODFISH. Well, that is to be determined. I have not seen the others yet.

The CHAIRMAN. You have not seen any except those which are on the streams?

Mr. BODFISH. No, sir; all I have found are on streams.

The CHAIRMAN. If you could find sites higher up, where the reservoirs could be constructed cheaply and safely, would it not be well to commence there and make your cheap reservoirs first?

Mr. BODFISH. I must say here, that the area that I have prospected over lies within the mountainous district.

The CHAIRMAN. I am speaking of the mountain district.

Mr. BODFISH. In the Arkansas Valley mountain district reservoir sites off the streams do not exist. It is a rapid-falling stream, and all of its tributaries are rapid-falling streams.

The CHAIRMAN. When you have surveyed and finished your work in the mountain regions, what surveys do you make for the purpose of ascertaining ditch lines, so as to show what lands will be under water when the works are constructed?

Mr. BODFISH. If the water is taken out of the streams directly below the mountain region, a trial line—what I would call a "fly" line—would be run from the point from which we wished to take the water out.

The CHAIRMAN. Would a topographic map be sufficiently accurate to enable you to dispense with that "fly" line or trial line?

Mr. BODFISH. If it was a good topographic map, well constructed, we might in some places dispense with the trial line.

Senator MOODY. You mean if it was a topographic map that was constructed under the supervision of an engineer, as an engineer would construct it?

Mr. BODFISH. Yes, sir.

Senator MOODY. It would have to be such a map, and not a mere topographic map—a map of the surface?

Mr. BODFISH. A general map of the surface may be good for general purposes, but not for specific purposes.

The CHAIRMAN. What proportion of the work on the Arkansas, for example, would be dispensed with if you had a good topographic map to begin with? How much cheaper would it be to make the irrigation survey if that preceded it?

Mr. BODFISH. I do not think it would be any cheaper, sir, in the Arkansas drainage basin.

The CHAIRMAN. You would have to do about the same amount of work at any event?

Mr. BODFISH. Yes, sir.

Senator REAGAN. If you had a topographic survey, would you have to make trial lines the same as you do without a topographic survey, in

order to ascertain the extent and character of a drainage basin and to establish the lines for ditches?

Mr. BODFISH. No, sir; not necessarily.

Senator REAGAN. If you would not, how do you make out that it would cost as much to make the irrigation survey with a topographic survey as without it?

Mr. BODFISH. As I understand it, a topographic survey means a survey of the whole district within the boundary lines of the drainage area.

Senator REAGAN. That is what I mean, the drainage area and the country to be supplied with water and irrigated.

Mr. BODFISH. Even having a topographic map of the entire area, and even with the rain-fall given, I would not know the quantity of absorption or evaporation on the surface.

Senator REAGAN. Would you know that by an engineering survey?

Mr. BODFISH. I could not determine the run-off of any stream.

Senator REAGAN. You could not determine that in any way except by hydraulic experiments.

Mr. BODFISH. I could determine, by measuring the streams, the amount of water that runs off.

Senator REAGAN. What I am trying to obtain from you is an explanation of the answer you made to the chairman, that it would not save any expense to have a topographic survey precede your irrigation survey.

Mr. BODFISH. If I had to do the same work after the topographic survey was made that I had to do before, it would cost more.

Senator REAGAN. But would you have to do it?

Mr. BODFISH. Yes, sir. As I explained to you just now, I would have to weigh the amount of water that passes a certain point, any way, even if I had a topographic survey of the area.

Senator REAGAN. If you had a topographic survey, would you not know the drainage basin from that?

Mr. BODFISH. Yes, sir.

Senator REAGAN. Would you not know where you could fix your dam from that?

Mr. BODFISH. Not necessarily. It would depend upon how well the map was made. I mean by that, that a map showing 20-foot contours would not necessarily——

Senator REAGAN. Would you not know the country that would be supplied by irrigation from a topographic map?

Mr. BODFISH. Not until I had located the reservoir. If I could not locate the reservoir from the map, I could not tell you what country I could cover.

Senator REAGAN. How do you get the information as to where you shall locate the dam and reservoir?

Mr. BODFISH. By personal inspection on the ground.

Senator REAGAN. And not a survey.

Mr. BODFISH. Yes, sir.

Senator JONES. I understood you to say a while ago that a topographic survey would save you from making examinations where it would be impossible to find reservoir sites.

Mr. BODFISH. It will in some cases, sir.

Senator JONES. Then there would be at least that shadow of difference between the cost of locating works with and without a topographic survey.

Mr. BODFISH. If the topographic map shows me the water flows over

a drainage line that falls a hundred feet to the mile, it is very little use for me to go there to find a reservoir site.

Senator JONES. It would be no use to go there to look for a reservoir site?

Mr. BODFISH. No, sir.

Senator JONES. If you found that out from a topographic map, even if you could find it without the topographic map, then you would save something by the use of the topographic map?

Mr. BODFISH. Yes, sir.

Senator JONES. Then you do save something by the use of a topographic map in such a case as that?

Mr. BODFISH. I stated that ——

Senator JONES. I understood you to say that there would be no saving in having a topographic map.

Mr. BODFISH. I referred to the entire work of examination and construction and not to special cases. If I have a map of the entire area, and by examining that I can ascertain that there is one-fourth or three-fourths of that area that I need not consider, so much of my time is saved, and even if I had to examine all of those streams, I think personal inspection would cost less than a topographic survey of the whole drainage basin.

Senator REAGAN. If you should make a topograhpic survey on a stream, would you not know from that topographic survey where the narrowest gorge was?

Mr. BODFISH. Certainly.

Senator REAGAN. The facts as to the character of the soil, of course, you get by inspection?

Mr. BODFSH. Yes, sir.

Senator REAGAN. If you know the location of the narrowest gorge which will create the largest basin, is that not where you will locate your reservoir dam?

Mr. BODFISH. Not necessarily.

Senator REAGAN. What would be the exception to that?

Mr. BODFISH. The fall of the stream above, or other facts—whether it will hold a sufficient quantity of water——

Senator REAGAN. You do not take my whole question. I say after you have ascertained your basin by the survey is it necessary to go over that again, or do you suggest the idea of guessing at it?

Mr. BODFISH. I would not send an engineering party there to make a special survey of that reservoir site without having personally visited and examined it to see whether it was represented right on the map.

Senator JONES. If you were making an examination of a given watershed for reservoir sites, without a map of any sort or of any description, would you have to make a personal inspection of the entire territory?

Mr. BODFISH. Yes, sir.

Senator JONES. How would that be made?

Mr. BODFISH. First, by myself riding over the country, or by having some intelligent assistant, to whom I could delegate part of that work, do it for me.

Senator JONES. By simply examining it with the eye?

Mr. BODFISH. Yes, sir.

Senator JONES. Then, when you found the location, approximating, according to your judgment, the conditions required, what more particular examination would you have to make to ascertain the facts in the case?

Mr. BODFISH. I send one of my parties there to make the actual survey and ascertain what different heights of dam are required—how much water different heights of dam will contain.

Senator JONES. What does the party do?

Mr. BODFISH. They make a minute contour map, showing 10 feet of elevation, and they make a careful topographic survey of the immediate location of the dam.

Senator JONES. How would the topographic survey which you would have made by that party differ from the topographic survey as made now under the direction of the geological survey for the purposes of irrigation?

Mr. BODFISH. It is made in the same manner, but with a great deal more detail.

Senator REAGAN. More detail as to the actual place of the reservoir?

Mr. BODFISH. The contour of the basin is shown more in detail.

Senator JONES. The principal work would be at the particular place where you intended to locate the reservoir?

Mr. BODFISH. Yes, sir.

Senator JONES. And the examinations of the outlying ground would be less minute?

Mr. BODFISH. Yes, sir.

Senator JONES. Would those outlying examinations be more minute than the geological survey?

Mr. BODFISH. Yes, sir.

Senator JONES. And you would examine the whole drainage basin?

Mr. BODFISH. No, sir; the whole storage basin—the storage basin caused by the dam.

Senator JONES. You misunderstood my former question. I asked you in the beginning as to whether your examination of the storage basin would be more minute; then I asked you if your examination of the outlying region would be less minute.

Mr. BODFISH. That would not be examined at all.

Senator JONES. You would not examine anything except the area of the lake you intended to make?

Mr. BODFISH. No, sir; but if I could not ascertain from the land office survey the boundary lines of that drainage basin, I would meander it in a crude manner sufficiently to determine what the drainage area was; but I see no necessity of making a topographic survey over that entire area, showing the contour.

Senator JONES. It would make no difference whether that was steep or level, or slightly rolling or anything of that sort?

Mr. BODFISH. Nothing more than my eye would show.

Senator JONES. Then, as I understand you, your idea is that the topographic examination made in connection with the geological survey for irrigation purposes is entirely useless?

Mr. BODFISH. It is not absolutely necessary at all, sir.

Senator JONES. And in the location of the reservoirs, you think all that is necessary is to survey exactly and particularly the location of the lake and nothing else, except to get, in a rough sort of way, a general idea of the size of the drainage basin?

Mr. BODFISH. Yes, sir.

Senator JONES. Without regard to its topography?

Mr. BODFISH. Yes, sir. If I weigh the amount of water passing that point, I can weigh it more cheaply, I can measure its flow and quantity more cheaply there than I could make a survey of the reservoir basin, and then I would know the amount of water passing that point——

Senator JONES. Have you any definite idea what caused the destruction of the Hassayampa dam?

Mr. BODFISH. I have never seen the place, or any good maps of it, and I have no opinion as to the matter.

Senator REAGAN. In the construction of a dam is it a matter of any moment to know whether the drainage basin from which the water is to be collected is precipitous or level?

Mr. BODFISH. Yes, sir.

Senator REAGAN. Do you get that information by the eye or by a topographic survey?

Mr BODFISH. By the eye, sir.

The CHAIRMAN. Is there anything further?

Senator JONES. I would like to ask a question or two. In locating these reservoir sites as you indicate, after you get them located, you then, in selecting a route for ditches to take the water to the land, run trial lines to ascertain the relative elevations of the country, do you not?

Mr. BODFISH. I have to determine approximately the fall per mile that I can give that ditch when making the final survey.

Senator JONES. And would you not also have to find out where it ought to be located?

Mr. BODFISH. That would be part of the preliminary work, to discover that point.

Senator JONES. Would a topographic survey save any part of that expense?

Mr. BODFISH. That would depend upon the accuracy of that survey.

Senator JONES. Of course an inaccurate and worthless survey would not be of any value in any way or anywhere. I was asking with reference to the topographic survey made by the Geological Survey in this matter. The object of this inquiry is this: It has been stated here by certain gentlemen that that portion of the money appropriated by Congress for furthering this survey of the arid lands that has been used for a topographic survey has been wasted and thrown away, and that only that part has been valuable that has been put into the hands of the hydrographers and those doing engineering work as such. Now, what the committee want to know is the opinion of the gentlemen engaged in this work as to the relative cost of obtaining this information by the two different methods. Your way, as I understand you, is to secure the information by going onto the ground and making trial lines. Others think that a topographic map of the entire country facilitates matters. What we want to know is the relative importance of these different branches of the work, and my immediate purpose in asking the question I did was to find whether there would be a saving of cost to your work or the work you did if you had such a map as is being constructed in this matter, to indicate to you where you should locate your lines from the reservoirs to the lands to be irrigated, or whether it would be cheaper to ascertain that by making trial lines; that is, by making a survey yourself.

Mr. BODFISH. I should prefer to make the trial lines.

Senator JONES. That does not quite answer my question.

Mr. BODFISH. Even with the maps in existence I should rather make the trial lines for my own personal——

Senator JONES. I was asking about the relative cost. The point I intended to ask you was whether the topographic survey would enable you to make a correct and proper location of the ditch lines without making all these trial line surveys?

Mr. BODFISH. I understand the question, sir, and when I said it would depend upon the quality of the map I stated the whole matter.

Senator JONES. What is the quality of the maps——

Mr. BODFISH. I do not know the quality of the maps made in the Arkansas district. I have not had a chance to test them.

Senator JONES. You know the quality of the maps being made by the Geological Survey, do you not?

Mr. BODFISH. I know what kind of maps they make elsewhere, but I do not know what they have made there.

Senator REAGAN. This does not apply to any particular locality. It is a general proposition.

The CHAIRMAN. You say you know the quality of the maps made by the Geological Survey elsewhere than in your district. State what that is.

Mr. BODFISH. I know the quality of the maps made by the Survey in the East and I know the quality of some of the coarser maps of the West, but I do not know what they are doing on this irrigation survey work in making topographic maps.

Senator JONES. If you are not familiar with the maps, of course you can not answer.

The CHAIRMAN. Have you examined any topographic survey maps, East or West, that would be sufficiently accurate to be of practical use in locating ditches?

Mr. BODFISH. I do not think I have, sir.

The CHAIRMAN. Have you examined many?

Mr. BODFISH. I mapped, with my assistants, a fourth of the State of Massachusetts.

The CHAIRMAN. Made a topographic survey?

Mr. BODFISH. Yes, sir.

The CHAIRMAN. Then you have been engaged in that work?

Mr. BODFISH. Yes, sir; for ten years.

The CHAIRMAN. And were none of the maps constructed under your supervision or by you sufficiently accurate to select ditch lines by?

Mr. BODFISH. No, sir.

Senator JONES. Of what value are those maps?

Mr. BODFISH, They are of general value.

Senator JONES. Tell me something they can be used for.

Mr. BODFISH. You could locate a preliminary railroad line by one.

Senator JONES. Then why could you not locate a preliminary ditch-line by it?

Mr. BODFISH. Because a ditch-line is a rigid line. A railroad line is not a rigid line; it is covered by a variety of grades, steep and light. A ditch line is comparatively a rigid line and can not be determined by anything but the lightest grades.

Senator JONES. Do you not run a preliminary line for a ditch like you do for a railroad and then make the permanent location of the ditch?

Mr. BODFISH. No, sir.

Senator JONES. You make the permanent location at once?

Mr. BODFISH. We make an approximate location by running a comparatively rigid line first.

Senator JONES. So that no secondary work is necessary.

Mr. BODFISH. Except for cross-sections and cost of construction. For instance, if I am to run a preliminary line as I did in Kansas; starting from near the Kansas and Colorado line, I ran a preliminary line to see where ditches could be run to take water from the Arkansas

River just west of the Colorado and Kansas line. A grade of about a foot and a half to the mile was determined upon before the line was run and a line leveled out and meandered out on that grade to see where it would go, how soon it would get on top of the bluffs, and where it would pass through those bluffs—whether through bad or good cuttings—and the deviation on the grade from one foot and a half was very little.

Senator JONES. If you had a similar survey to that you made in Massachusetts for that particular section of country you went over could you have determined with approximate certainty whether or not that ditch was feasible, without making your survey?

Mr. BODFISH. I should not have assumed to use my Massachusetts work for that purpose without running a random line over the ground.

Senator JONES. Then if there had been just such a survey of that country as you had made in Massachusetts, it would have been of no practical use or value in determining whether or not that ditch line was feasible?

Mr. BODFISH. No, sir; it would not have been of much value.

Senator MOODY. In your surveys in the Arkansas River district did you make use of any topography that had been executed in that district?

Mr. BODFISH. No, sir.

Senator MOODY. Then whatever work the engineer corps has done with reference to irrigation has been done entirely independently of any topography?

Mr. BODFISH. It has in the Arkansas division.

Senator MOODY. Do you know of any other division where topography has been used?

Mr. BODFISH. I do not know anything about what has been done in the other divisions, sir.

Senator MOODY. Of course I understand that you want to answer accurately; your mind runs in that direction; but do you know, in a general way, of any use that has been made of the topography that has been going on under the geological appropriation or under the irrigation appropriation?

Mr. BODFISH. I do not know of any use that has been made of it.

STATEMENT OF GEORGE E. CURTIS, METEOROLOGIST AND HYDROGRAPHER U. S. IRRIGATION SURVEY.

The CHAIRMAN. Mr. Curtis, what is your occupation?

Mr. CURTIS. Meteorologist and hydrographer.

The CHAIRMAN. Where have you been engaged in that occupation?

Mr. CURTIS. In the Geological Survey.

The CHAIRMAN. How long?

Mr. CURTIS. In the office since last June; in the field since the preceding December.

The CHAIRMAN. What section of the country were you in?

Mr. CURTIS. Colorado and New Mexico.

The CHAIRMAN. What are the duties of a hydrographer?

Mr. CURTIS. The duties of a hydrographer are mainly to measure the discharge of steams.

The CHAIRMAN. What particular duties did you perform? Were you measuring the streams?

Mr. CURTIS. While I was in the field my duties were in connection with a camp of instruction for hydrographers, and after having finished those duties I returned to the office.

The CHAIRMAN. What is a camp of instruction?

Mr. CURTIS. It is for the instruction of young hydrographers who are about to take the field in different parts of the West. My duties were to give instruction in meteorological and hydrographic observations.

The CHAIRMAN. Explain, in brief, how you ascertain the flow or discharge of water in a stream at a particular point.

Mr. CURTIS. A cross-section is selected at which the river has a uniform slope, and which is a region both of minimum deposition and of minimum corrasion. Soundings are made, and the cross-section is divided into partial sections whose area is computed. The average velocity of the current is then measured with the current meter in each partial section. From its known area, and from the average velocity of the current, the discharge through each partial section is computed, and the sum of the partial discharges is the total discharge of the stream.

The CHAIRMAN. Can you tell from what the velocity is when the water is low what it will be when the water is high?

Mr. CURTIS. No accurate determination can be made except by actual measurement.

The CHAIRMAN. The velocity of the water is influenced by the water coming into contact with the land, either on the sides or on the bottom of the stream?

Mr. CURTIS. The friction and the slope.

The CHAIRMAN. When the river is high the middle of the stream has less friction than the sides and bottom. How can you estimate for that?

Mr. CURTIS. The velocity is determined in different sections of the stream at every gauging, and gaugings are made at as many different stages of the stream as possible.

Senator JONES. How do you determine that? By actual measurement?

Mr. CURTIS. By actual measurement with the current meter.

The CHAIRMAN. Then you must examine the stream at flood times?

Mr. CURTIS. Yes, sir; at all heights.

The CHAIRMAN. That would take a great many years?

Mr. CURTIS No, sir; in a usual year the——

The CHAIRMAN. There have been several great floods on the Pacific Coast. There was one in 1849, another in 1861, and one this year—a great flood, overshadowing the others. How do you ascertain the facts for such years?

Mr. CURTIS. Those are unusual cases.

The CHAIRMAN. But they must be obtained.

Mr. CURTIS. If not measured, the discharge at such times can only be estimated, but frequently estimated with considerable precision.

Senator JONES. Do you find that the same amount of water is discharged at the same flood-height at all times? For instance, if you have a gauge in a river, would the discharge at the 20-foot mark be the same at all stages?

Mr. CURTIS. Not necessarily; in fact, in some large rivers, as for example the Mississippi, it has been found that the discharge is different in rising from what it is in falling water.

Senator JONES. Is there a difference at different periods of a rise as to the amount of discharge at a given point?

Mr. CURTIS. If I understand you, those are fine questions that are of little economic value; they are principally of scientific interest or important in connection with river hydraulics.

The CHAIRMAN. What use do you make of the topographic maps in hydrography?

Mr. CURTIS. None, in the actual conduct of the work.
The CHAIRMAN. You rely upon your measurements of the streams?
Mr. CURTIS. Entirely.
The CHAIRMAN. Are you a practical engineer?
Mr. CURTIS. No, sir.
The CHAIRMAN. You are simply a hydrographer?
Mr. CURTIS. Yes, sir; and meteorologist.

FURTHER STATEMENT OF EDWIN S. NETTLETON, SUPERVISING CIVIL ENGINEER ROCKY MOUNTAIN REGION, U. S. IRRIGATION SURVEY.

The CHAIRMAN. I believe you have already given your opinion that it is not necessary that a topographic survey should precede the engineering survey for irrigation.
Mr. NETTLETON. I have.
The CHAIRMAN. How much use could you make of an ordinary topographic survey in the engineering work?
Mr. NETTLETON. To an engineer entirely unacquainted with the country a good map would be somewhat of a guide to study in his office before entering the field, but after that I do not think it would be of much or any value to him; that is any topographic map that I have seen made in this country.
The CHAIRMAN. Have you examined the topographic maps that have been made by the Geological Survey?
Mr. NETTLETON. Yes, sir.
The CHAIRMAN. Pretty extensively?
Mr. NETTLETON. Yes, sir. I have lately looked over pretty nearly all of the maps, including all the western ones that are published.
The CHAIRMAN. When they make a topographic survey of a section and then of another adjoining section, how do they join their work together?
Mr. NETTLETON. I am not familiar with the way only from what I have been told and from some work I have seen in the office. The work of making these surveys is done by a great many different small parties who are sent out into the field. Their work is sent into the office in sheets, covering small areas, and the sheets are adjusted one to another; and it has been found in practice, I think, that different topographers will not complete the contours on their sheets so they will join. Many times there are considerable errors, and those have to be adjusted in the office.
The CHAIRMAN. They average them?
Mr. NETTLETON. Yes, sir.
The CHAIRMAN. Bring the lines together?
Mr. NETTLETON. They are made to represent a picture with a reasonable degree of accuracy.
The CHAIRMAN. That is done for the purpose of learning the general geography and topography of the country?
Mr. NETTLETON. Yes, sir.
The CHAIRMAN. Made up in that way, as I understand you, they would not be of any practical use in the accurate survey needed for irrigation?
Mr. NETTLETON. I consider the work of locating and surveying reservoirs and establishing lines of canals as being work that requires greater refinement than it is possible to secure with a topographic sur-

vey like we are doing or can afford to do. For instance, in the mountains the contour lines are supposed to be 50 feet, vertically, apart. In computing a gradient of less than 50 feet in a mountain country, in order to establish reservoirs or ditch lines, it is necessary to make observations and computations of which no note can possibly be taken from a topographic map. Contour lines 50 feet apart might omit to show a proper reservoir site, because the reservoir site might be only 40 feet high.

Senator REAGAN. You mean 40 feet of altitude?

Mr. NETTLETON. Yes, sir; vertical height.

The CHAIRMAN. That is the scale, I believe, on which they are making their topographic maps in the mountains?

Mr. NETTLETON. Yes, sir; 50 feet.

Senator REAGAN. Do you know what scale is employed generally by the topographic survey on the lower lands?

Mr. NETTLETON. I think 20 feet is the smallest scale they are working on, but I am not certain about that. I think the scale is 20 feet on the plains and 50 and 100 feet in the mountains. I am not positive as to the exact scales.

Senator REAGAN. If the maps were made on a scale of 10 or 12 feet, would that make a difference, in your opinion?

Mr. NETTLETON. I do not think that even would be sufficient.

Mr. REAGAN. I am not talking about the details.

Mr. NETTLETON. It would be of greater assistance. Ten or 12 feet contours in the mountains would show the possible existence of a great many more reservoir sites than 50-feet lines would.

The CHAIRMAN. But after knowing the possible existence of sites, what would be necessary to know actually what could be done in each particular case?

Mr. NETTLETON. To make what we call the engineering survey, or a topographic survey sufficient in detail to determine the area and holding capacity of that reservoir.

The CHAIRMAN. Do you invariably visit and inspect the ground before you make any survey?

Mr. NETTLETON. Yes, sir. In regard to reservoir sites in the mountains, a practiced engineer can generally determine with his eye, without the aid of instruments, what is a possible reservoir site and what is not; but generally the engineer looking for reservoir sites or making preliminary examination has a hand-level. He can get onto a suitable point and tell very nearly with his hand-level where the water line will be; and standing on one side of a dam site he can trace pretty near the water line. If that shows an area sufficient, and the dam can be made without too great expense, then he orders a survey. That survey is made accurately enough to determine quantities in the dam, the cost of making the dam, and also the holding capacity of the reservoir.

The CHAIRMAN. Where you construct reservoirs sufficiently strong to withstand floods, what elements or facts must be taken into consideration?

Mr. NETTLETON. There are two ways of providing against floods. One is by an overfall dam, which must, of course, be made very secure on its back side and on its foundation. Another is, where the floods are not very torrential and where the discharge of the stream can be provided for by making a waste-way lower than the crest of the dam, leading off to one side or one end of the dam.

The CHAIRMAN. Where you use a waste-way the question will be in getting it large enough for all possible contingencies?

Mr. NETTLETON. Yes, sir. The experience of the last year or so leads me to believe that that matter has not had sufficient study; that we have not paid sufficient attention to the occurrence of heavy storms and sudden floods; but the destruction of the two dams that have recently occurred ought not to be used as an argument against constructing reservoirs.

The CHAIRMAN. Why not? That is a question that concerns the public very seriously.

Mr. NETTLETON. In the case of the Johnstown disaster, the waste-way was evidently large enough to carry off the flood that caused the destruction of that dam; but that was an unprecedented storm—seven inches of rain fell within a few hours on that drainage area. The reservoir was used for fishing purposes, and in the waste-way a grating of iron rods an inch in diameter, set very close together, had been put in to keep the fish from running down the stream. This tremendous storm brought down leaves and brush, and one large log, which lodged against this grating. The man in charge, or the only man who was there having any authority, was a young engineer, who, instead of blowing out the waste-way with dynamite or some other explosive, commenced to raise the embankment of the dam, which had settled and was low in the middle. He commenced putting loose earth on the top, and the water raised faster than he could raise the dam; at the same time the outlet was partially choked up with this rubbish. It is my opinion that if that grating had been taken out and the waste-way kept clear there would have been no disaster.

The CHAIRMAN. Then, in ordinary dams you would not have those fish-traps?

Mr. NETTLETON. No, sir. I would do just the opposite. There are places in the old country where they put the waste-way very considerably below the crest of the dam. Then if they want to utilize nearly the whole capacity of the dam, they put up posts and some kind of temporary wicker work of straw, that will hold the water until it gets to a certain height. When it gets to that height it will break away—go out before the water rises to the top of the dam, and that leaves a very large opening for the protection of the dam——

The CHAIRMAN. Have you any knowledge of this other disaster which occurred in Arizona?

Mr. NETTLETON. Nothing except what reports I have seen in the newspapers. But that was evidently caused by an insufficient waste-way, causing the water running over the top of a loose-rock dam.

The CHAIRMAN. It was constructed for an overflow dam?

Mr. NETTLETON. No, sir; it was not so designed——

The CHAIRMAN. And the waste-way was not sufficient to let the water go by?

Mr. NETTLETON. No, sir.

The CHAIRMAN. Do you not think that is one of the things you have got to examine with great care?

Mr. NETTLETON. Yes, sir. I think one of the most important things in locating dams in running streams is in the first place to get the history of the stream, and if you can not get information in relation to the greatest floods that have occurred, observe the highest water-marks that can be found.

The CHAIRMAN. Mere gauging will not give you that information?

Mr. NETTLETON. No, sir, except in an exceptionally high stage of the water. I would provide for the greatest discharge ever known on the stream, and that to make it safe, I would double that capacity, in

case there was a great deal of property or many lives depending on the breaking of the dam. Such things do not cost very much.

The CHAIRMAN. You can in no stream make the waste-way sufficiently large to take a flood through.

Mr. NETTLETON. A waste-way is not always the best way to get rid of floods. Sometimes the best way is to take the water over the crest in whole or in part.

The CHAIRMAN. The overflow dams are very expensive, are they not?

Mr. NETTLETON. If you have solid rock for the foundation of your dam, and rock for the overflow water to strike on, a masonry dam is not very expensive.

The CHAIRMAN. Are there not some streams in the West where any dams, even masonry dams, would be unsafe; for instance, those streams where they have landslides in consequence of cloudbursts, which bring down immense bowlders?

Mr. NETTLETON. There are places in the mountains where I think it is unwise to try to dam those torrential streams. In the first place, the dams are of no use after you get them, filling up with sand and debris and making an over-fall dam without any holding capacity.

The CHAIRMAN. Do those mountain streams carry evidences on the ground that such floods have occurred, as a usual thing?

Mr. NETTLETON. Yes, sir. An engineer can generally find high-water marks.

The CHAIRMAN. And large bowlders which have come down the stream?

Mr. NETTLETON. Yes, sir. Especially where there is timber growing, you will frequently find the trees scarred and flood-wood lodged in the crotches of the trees, high above where one would suppose water ever could have reached, but yet it is there.

Senator MOODY. You are acquainted with these topographic maps that have been made by the Geological Survey?

Mr. NETTLETON. Yes, sir; I have seen them.

Senator MOODY. What use can be made of those in the Land Office in fixing the boundaries and the area of the reserved lands provided for?

Mr. NETTLETON. These topographic maps show only the topography of the country, without any reference to or connection with the Land Office surveys; and they give no information as to the character of the soil, whether or not it is a timber or rock covered country or irrigable and agricultural lands. They just simply show its slopes, and what the character of its slopes are. While a topographic map might show a fairly good looking country, still the land might not be worth segregating.

Senator MOODY. What use has been made of any of those maps in the selection of irrigable lands in the Land Department?

Mr. NETTLETON. I do not know that any use has been made of them.

Senator MOODY. What sort of maps do they have to have, and what sort of work do they have to do, in order to segregate the lands under this last appropriation of 1888?

Mr. NETTLETON. The only use of any map that I know of is one on which to make note of the lands segregated, the sections, etc.

Senator MOODY. Do those segregations have to be made entirely independently of any topography?

Mr. NETTLETON. Yes, sir; the segregations have to be described by township, range, section, and fraction of section, and have no connection whatever with topographic maps.

The CHAIRMAN. In order to make the segregation, it is necessary to make an actual survey on the ground, is it not?

Mr. NETTLETON. Yes, sir.

Senator REAGAN. Segregation for what purpose?

The CHAIRMAN. To ascertain what are and what are not irrigable lands. In order to accomplish that you would have to run a line on the ground any way?

Mr. NETTLETON. To connect that land with the present surveys?

The CHAIRMAN. With the Land Office surveys.

Mr. NETTLETON. Yes, sir.

The CHAIRMAN. If the topography were ever so accurate, it would not indicate the character of the soil, would it?

Mr. NETTLETON. No, sir.

The CHAIRMAN. And a line would have to be run to determine that?

Mr. NETTLETON. Yes, sir.

Senator MOODY. Would a topographic map indicate the character of the ground where the ditch has to be run?

Mr. NETTLETON. Only as to the slopes, but not as to whether it is sandy or alluvial soil.

Senator MOODY. It would not indicate whether the soil was rocky?

Mr. NETTLETON. It shows nothing except the slopes and the natural water courses.

Senator MOODY. In running the line of a ditch to carry water from a reservoir, would you or would you not take into consideration the character of the soil as to rocks and so on through which that ditch would run?

Mr. NETTLETON. Certainly we would have to consider that.

Senator MOODY. Would you not avoid, if possible to do so, in your engineering determination a region of country where the soil is composed of rocks, broken up or loose?

Mr. NETTLETON. I would avoid any country that would prevent the building of a practical ditch.

Senator MOODY. What use could be made of one of those topographic maps in locating the line of a ditch?

Mr. NETTLETON. In the actual location of the lines of ditches it would be of no use whatever.

Senator MOODY. In locating a reservoir, would you not take into consideration the character of the foundation ot the banks?

Mr. NETTLETON. Yes, sir; certainly.

Senator MOODY. What use can be made of a topographic map for that purpose?

Mr. NETTLETON. It furnishes no information whatever in regard to the practicability of a dam site, or the character of its sides or bottom, which is one of the most important things to be considered in the construction of a dam. It simply shows what the slopes of the country are.

Senator MOODY. Can you not ascertain by the eye, with a sufficient degree of accuracy for engineering purposes, the location of reservoir sites preliminary to the actual and accurate survey?

Mr. NETTLETON. An engineer with good judgment can very closely estimate what is a reservoir site and what is not. He may not be able to determine whether it is entirely practicable. Perhaps the dam may cost too much for the amount of water it will hold. He can not determine those questions finally unless he makes a survey.

Senator MOODY. I mean, would you gather those facts by observation, preliminary to the actual and accurate detail survey?

Mr. NETTLETON. Most certainly.

Senator MOODY. Of what service would a good topographic map be in making those examinations?

Mr. NETTLETON. As I stated in the beginning, it might be of some assistance to an engineer who was a stranger in the country, by enabling him to get a general idea of the country; but in actually locating reservoirs, I do not think the topographic maps I have seen would be of any assistance.

Senator MOODY. Neither in locating reservoirs or in the line of ditches, nor in the segregation of the irrigable lands.

Senator JONES. Nor in the ascertainment of the sites for reservoirs.

Mr. NETTLETON. There are some reservoir sites that might be shown by such a map; for instance, take the one at El Paso. If there had been a topographic survey of that, with 20-foot contour lines, it would have shown without question that there was a reservoir site there; but there are thousands of other localities where 50-foot contour lines would not show nearly all the reservoir sites.

Senator MOODY. Will you please state any instance where the irrigation engineering service has reaped a benefit from the use of the topographic survey that has been going on?

Mr. NETTLETON. Well, I have had something to do with the starting out of two or three of the engineers on this survey. In the first place I sent to Washington (I was then at Denver) for all the maps of the country that was in my division. I had the Hayden Atlas, which survey covered Colorado, and I got some topographic maps of Arizona and New Mexico, and a few of Montana up about the Yellowstone. Now, I do not claim that I can read topography on a map as readily as some, but I looked those all over, and with one or two possible exceptions I could not find on any of them what I could safely say was a reservoir site, so that I could direct or recommend an engineer to examine it.

Senator MOODY. In the process of exploring and developing the possibilities of irrigation through the means of artesian wells, of what use will be the topographic work which is being carried on by the Geological Survey?

Mr. NETTLETON. I think that perhaps in connection with artesian wells it would be more useful than in the engineering work of selecting reservoir sites and dam sites, because those maps show approximately the elevation above the sea, and in studying an artesian country it is quite desirable to know the altitude of the surface of the country above the sea-level within a reasonable degree of accuracy.

Senator MOODY. In making those explorations and investigations what would the engineer have to do?

Mr. NETTLETON. Without a topographic survey he would naturally get the profiles of the railroads crossing the country, all of which have the elevations above the sea-level. From the railroad profiles it is possible to get the elevations at every mile, but you can always get them without a great deal of trouble at every town along the line of a railroad. These furnish a good basis to work on. I did a good deal of that work in 1868. Commencing in southern New York I carried it down through the oil region in Pennsylvania, and I worked up my surveys from the railroad elevations of the different stations.

Senator MOODY. Is that not entirely sufficient for making examination in regard to irrigation by means of water obtained from the artesian basins?

Mr. NETTLETON. If you had a series of contours carried all over the country, with benches established, that would be of great advantage over the railroad elevations.

Senator MOODY. Is it essential in regard to practical demonstration?

Mr. NETTLETON. No, sir.

Senator MOODY. Can it not be done very much more cheaply without it?

Mr. NETTLETON. Yes, sir.

Senator MOODY. It would be a very expensive process to undertake to carry contour lines all over that semi-arid region 50 or 100 feet apart, would it not?

Mr. NETTLETON. I do not know what the cost would be per square mile for such work. Do you, Mr. Bodfish?

Mr. BODFISH. From $1 to $5 per square mile.

Senator JONES. It would cost that for a topographic survey?

Mr. BODFISH. Yes, sir.

Senator MOODY. Do you regard it as essential in making the examination for artesian basins throughout North Dakota, South Dakota, Nebraska, Kansas, and Texas, to have a topographic survey?

Mr. NETTLETON. No, sir; I have been considering that subject, and have looked up the railroad lines crossing that country, and I find a great number of railroads, especially near the Missouri River, through the eastern part. There are several lines running east and west which give an excellent opportunity of getting the profiles of that region.

Senator MOODY. So that you can make a pretty good guess as to the depths at different points of this artesian basin?

Mr. NETTLETON. Yes, sir.

Senator MOODY. Now, has it not been your experience, after all, that it requires the actual sinking of wells at different points to ascertain accurately the facts as to the depth of that basin?

Mr. NETTLETON. Yes, sir; whatever data you find by a bore you know to be true; whatever you theorize on you do not feel so sure about.

Senator MOODY. Is it not a fact that the roof of this artesian basin is very irregular, so that in some places you would have to sink very much deeper than in others, although at the same altitude?

Mr. NETTLETON. In my study of the oil country I found a very uniform character of rocks 1,000 or 2,000 feet below the surface, but nearer the surface they were more broken.

Senator REAGAN. If you were going to use the water of a particular stream to irrigate a particular plain, supposing there was no topographic survey or anything else to aid you, what steps would you take in order to apply the water to the land?

Mr. NETTLETON. The first thing to be done is to determine what land you want to irrigate; the next thing to be done is to determine whether you have water that can be carried onto that land.

Senator REAGAN. Determine the irrigation basin?

Mr. NETTLETON. Yes, sir. Then, if there is more land than water, and money saving is an object, we seek the cheapest line, because the amount of irrigation that can be done is limited on account of the amount of water; so we pick out the most economical canal. But if it is the other way, if there is more water than land, and it is desirable to cover every acre of land, then we try for the highest line possible to get onto that land, without so much regard to expense.

Senator REAGAN. What steps do you take to ascertain the extent and character of your catchment basin from which you get your water?

Mr. NETTLETON. We generally take the maps of the country. That is one guide. Another is a knowledge of the character of the stream obtained by observations or by inquiring of people who have known t

stream for years, and who know about what its discharge is. For irrigation purposes it is not so much the size of the drainage area as its character that we rely on.

Senator REAGAN. Do you regard it as essential to the success of such an undertaking that you should know the extent of the drainage area?

Mr. NETTLETON. Yes, sir.

Senator REAGAN. How would you get that?

Mr. NETTLETON. I think in nearly the whole country in the arid region we have maps of some kind that give very closely the drainage system of the region. They are compiled, as far as they have been made, by the Wheeler, the King, the Powell, and the Government land surveys. These maps show quite closely the areas of the drainage basins of the streams.

Senator REAGAN. Now, if there was a topographic survey made in the way that it is being made by the Geological Survey, could you not take those maps and locate the drainage areas and the lands that are to be covered by water?

Mr. NETTLETON. It would be relocating it. It would be simply confirming what has already been mapped; but I do not think that as to the areas it would change very much the areas of the drainage basins of the maps already made. It would give more information, perhaps, in regard to the slopes of the various parts of the country within those drainage basins; but the exterior lines of the drainage areas would not be changed very much, I think, by a topographic survey such as is now being made.

Senator REAGAN. Would you regard it as important, in determining a drainage basin, whether it was a level or precipitous country, with reference to the construction of your dam?

Mr. NETTLETON. It would if a man went into that kind of work without looking before and around him, and if he had no idea of his own as to the country he was in; but when an engineer is sent into a country he can generally see pretty well its general character.

Senator REAGAN. You think a good engineer could judge of the country without the assistance of the map?

Mr. NETTLETON. He ought to.

Adjourned.

STATEMENTS OF CHEMISTS REFERRED TO BY ASSISTANT SECRETARY WILLITS.

UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF CHEMISTRY,
Washington, D. C., February 3, 1890.

Hon. EDWIN WILLITS,
Assistant Secretary:

SIR: In addition to the information contained in the letter of May 7, which I hereby return, I would desire to call the attention of the committee to the fact that the character of the water used for irrigating purposes has much to do with the ultimate influence of irrigation upon the soil. If the water used for irrigating purposes contain much mineral matter, there would be a tendency for this matter to accumulate in the soil in such quantities as to become injurious to the growing crops. In many places where irrigation has been attempted with water charged with alkali it has had to be abandoned on account of the effect of the alkali mentioned above. Any attempt, therefore, to store water for irrigation purposes or to irrigate on a large scale should be preceded by a preliminary study of the nature of the water supply to be used.

The records of the Geological Survey abound in material of this description, that institution having made a systematic examination of the waters in the region embraced in the description contained in the committee's letter.

If the water, which is to be stored for irrigation purposes, come in the rain-fall it would usually be pure enough for irrigation purposes, provided it did not fall upon land already saturated with alkali. It is easy to see, however, that a body of water collected from the rain-fall descending on lands thoroughly charged with alkali might be wholly unfit for irrigation purposes. On the other hand, waters which are derived from large rivers and other streams are usually pure enough for irrigation purposes and could be used a long time on land without appreciably increasing the mineral constituents thereof.

Respectfully,

H. W. WILEY,
Chemist.

UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF CHEMISTRY,
Washington, D. C., May 7, 1889.

Hon. EDWIN WILLITS,
Assistant Secretary:

SIR: Your communication of the 4th instant, addressed to Dr. Wiley, chief chemist of this division, has been referred to me for a reply, Dr. Wiley's trip to the West in the interest of the sorghum experiments preventing him from taking up the subject to which you refer.

I have examined the letter of Senator Stewart, which I return herewith, and have the honor to make the following report thereon:

That portion of the inquiry included under the character and constituents of soils seems to be the only point which falls within the province of this division. In order to enable you to furnish the committee with information which would be useful to them on this point, I have examined all the literature which is here available for information in regard to the constituents and character of soils west of the hundredth meridian of west longitude. I find several extensive investigations upon soils in this area and considerable information upon their character, and will make reference as follows to the sources where it can be found:

(1) The soils of the different districts in California have been made the subject of a very complete and important investigation by Prof. E. W. Hilgard, State chemist of California and professor of agriculture in the University of California. This investigation was undertaken for the Superintendent of the Tenth United States Census, and is embodied in volumes 5 and 6 of the Tenth Census under the head of "Cotton production." The investigation was intended especially to make comparison of the soils of California with those of the Southern cotton-growing States, with a view of investigating the adaptability of the California soils to cotton production. It comprises a large number of analyses of California soils taken from various localities, and a very complete and able discussion not only of the character and composition of these soils, but also of their geological sources and formation. The composition of soils of the various cotton-producing States is included in the investigation; also a

large number of analyses of soils in the Indian Territory. Further elaboration and discussion of the subject of California soils by Professor Hilgard will be found in the different reports made by him to the president of the University of California, notably in the reports for 1882 and 1884. Appendix No. 7 to the report for the year 1886 contains a valuable treatise by Professor Hilgard upon "Alkali lands, irrigation and drainage in their mutual relations."

I can commend the general plan and character of this investigation to the Senate committee as a model of the manner in which such an inquiry may be profitably carried on.

(2) The annual reports of the United States Department of Agriculture contain considerable information upon the subject of the composition of soils, and I have searched them through to obtain all the data upon soils in the region which forms the subject of the investigation by the Senate committee. The annual report for 1870 contains, on page 100, the analyses of three samples of soil from western Nevada. A special report of the Department of Agriculture, issued in 1882, entitled "Investigation of Sorghum as a Sugar-Producing Plant," contains on pages 58 and 64 analyses of a number of samples of soil from the Arkansas Valley in Kansas, namely, Great Bend and Hutchinson, Kans., and from Rising City, Nebr. In the year 1886 Bulletin No. 10 of the chemical division of this Department was issued, having for its subject "Principles and Methods of Soil Analysis," by Mr. Edgar Richards, assistant chemist. This publication contains the analyses of a number of soils, including prairie soils from Dakota, and also soils from Washington Territory.

Besides the above I would state that the chemical division is at present engaged upon the analysis of a large number of soils collected from different parts of the country, among which are included four samples of soil from Arizona, one from California, and three from the Territory of Wyoming. These analyses will be completed some time during the course of the present year, and the results can be communicated to the committee if they so desire.

(3) In addition to the above information on the subject of the character and composition of the soils within this region, it might not be improper to suggest to you that the attention of the committee be called to the sorghum plant as one peculiarly adapted to certain portions of the region which forms the subject of the committee's investigation. It might be well to forward to the committee, as part of the information to be furnished from this Department, the special bulletins containing the results of the experiments of the Department upon sorghum as a sugar-producing plant. Some of the best results in the growth of sorghum were attained last year in the southwestern portion of Kansas at the station of this Department at Conway Springs. Both these and previous experiments by the Department would seem to show that the sorghum plant is peculiarly adapted to the arid or subarid regions of the West. It resists drought much better than corn or the other cereal crops, and seems, moreover, to attain a higher percentage of sugar in these dry regions.

I would also respectfully call your attention to the report, upon which, however, I can give you no exact information, that the tropical sugar-cane is said to have been raised with considerable success during the past season upon irrigated lands in Arizona.

Respectfully,

C. A. CRAMPTON,
Acting Chemist.

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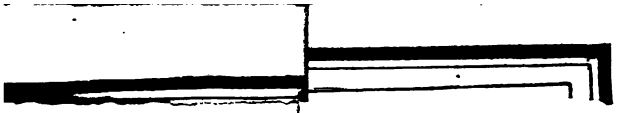

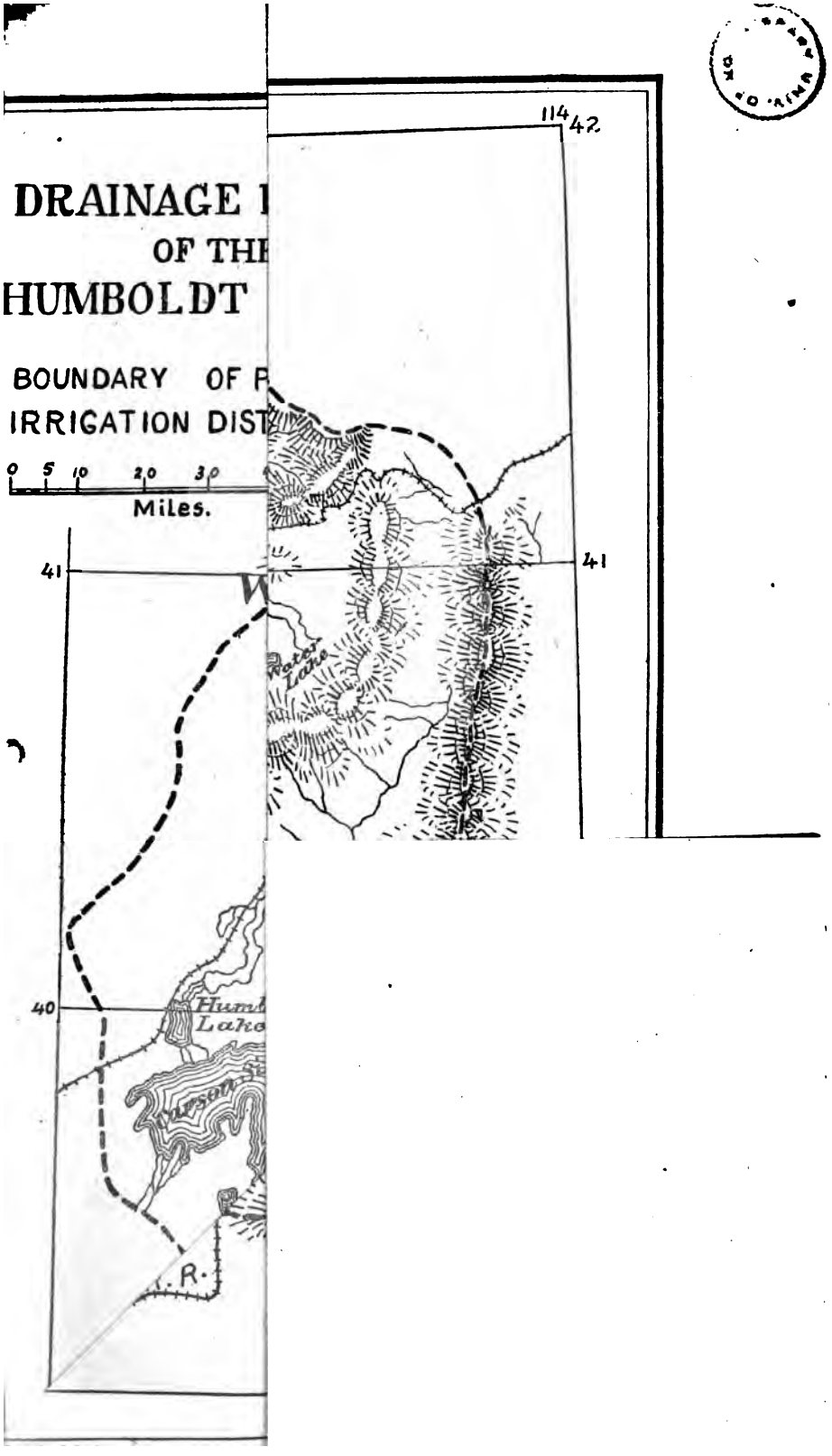
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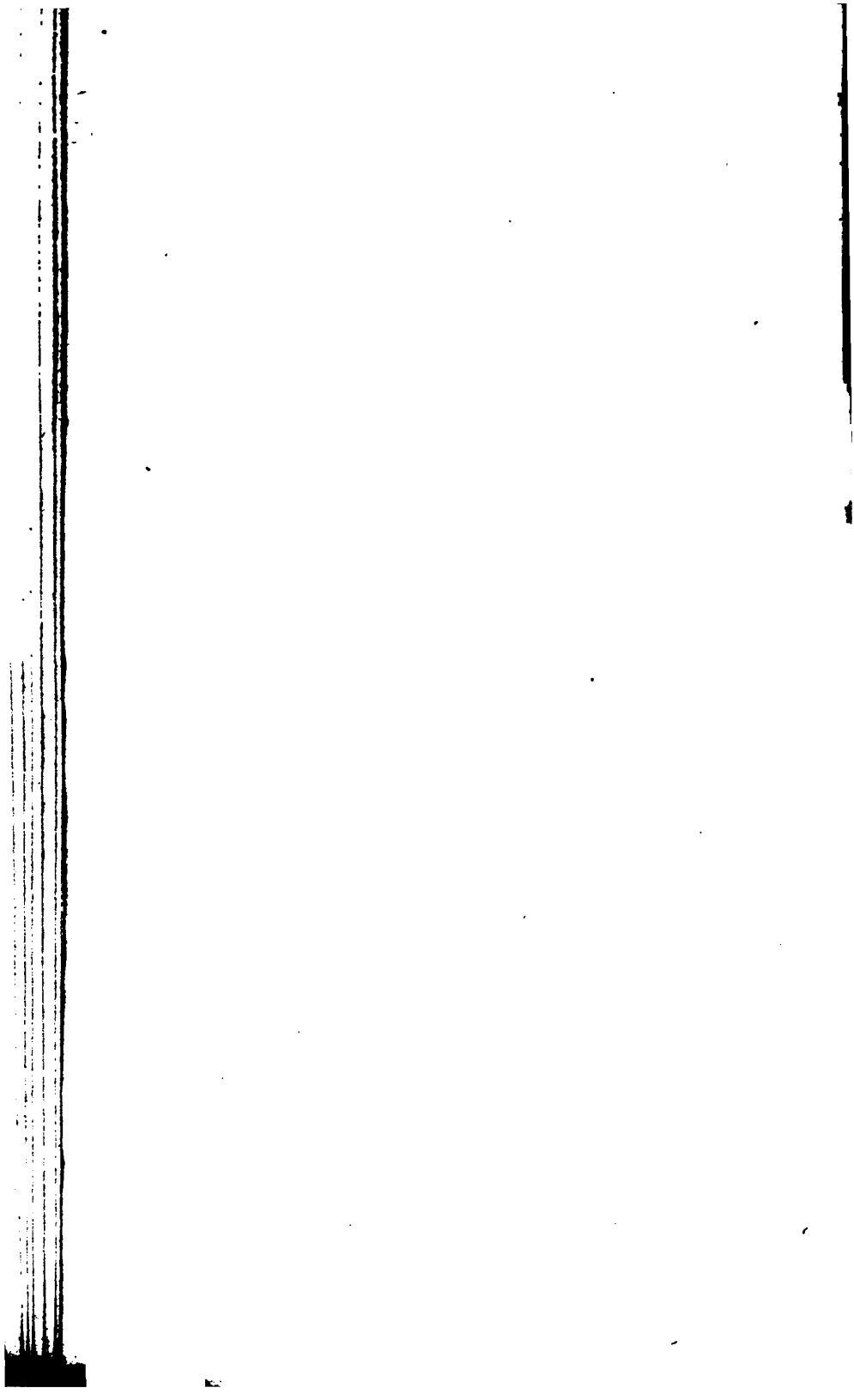

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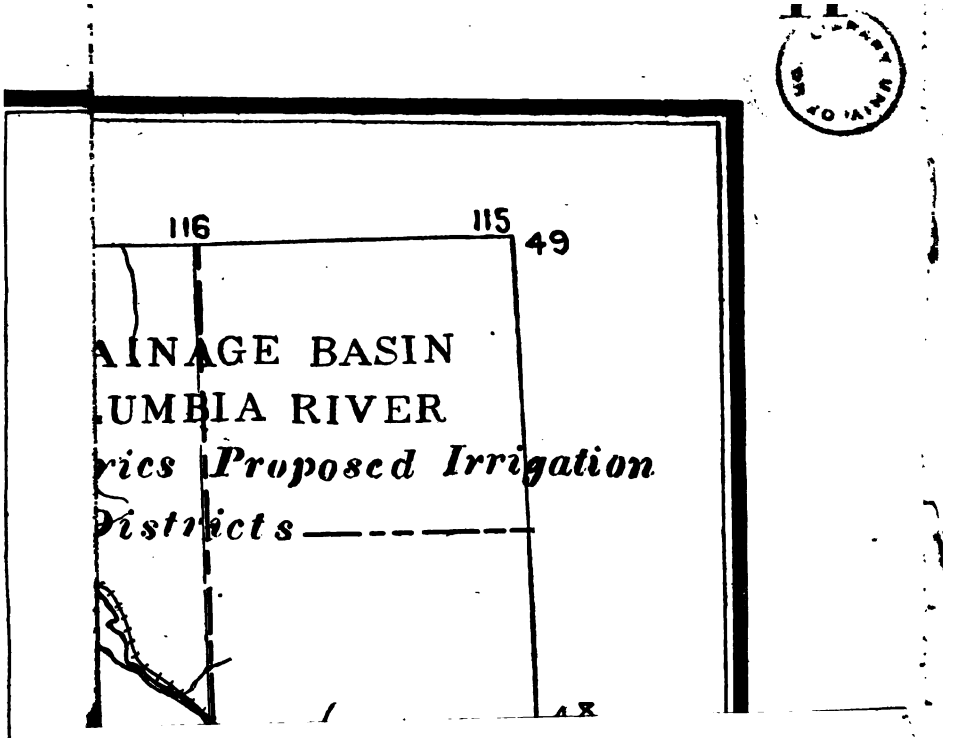
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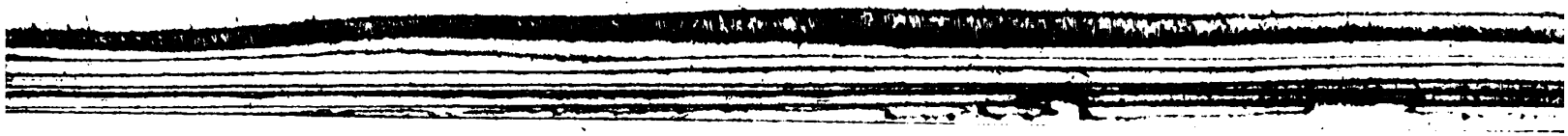

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MISCELLANEOUS PAPERS.

MISCELLANEOUS PAPERS.

ESTIMATE FOR EXPENDITURES OF SURVEY.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., February 7, 1890.

DEAR SIR: Agreeably to a promise made you I herewith submit for your consideration an estimate of the cost of the field work of the Irrigation Survey for the fiscal year ending June 30, 1891, which includes the cost of doing the work and collecting the information that in my judgment is required by the law making appropriations for this specific work.

The estimate does not include the salaries of administrative officers above the Chief Engineer, nor the expenses connected with the publication of the necessary maps and reports, or the expenses for office rent in Washington and incidentals connected therewith.

After a careful consideration of the question regarding the time required to complete the surveys, and the ultimate cost thereof, I am of the opinion that five years will be ample time in which to cover the whole country with the necessary field work. Another year will be required to finish the office work and make the final field reports. In placing the time at five years I have endeavored to consider the immediate necessity for pushing the work with due regard for securing good results and with minimum expenditure of money.

I have designated the allotments for each State and Territory, but this may not be considered as at all arbitrary. This can also be said in reference to the total amount.

The semi-arid portion of our country needs something more than is contemplated in the present law. This section requires artificial water many times to tide over a few weeks of scanty rain-fall. There are no "waters in sight," and grave engineering difficulties present themselves when undertaking to supply it with the common methods for irrigation. There are several theories as to how the waters not "in sight" can be utilized. It is probably wise for the Government to undertake the solution of some of the most reasonable of these theories.

If the subject of climatological observations are to be taken up by the survey, as was suggested to the Senate committee at its last meeting, I would add at least $10,000 for this purpose.

If deemed wise, the appropriation could be made in bulk and then, if other considerations were to be taken into account, the expenditures could be locally changed.

I should suppose $75,000 would cover fully all unprovided salaries, office rent, the printing of maps, reports, etc., making in all $470,000. The appropriation for the first year will be larger than that for subsequent years on account of the purchases of instruments, field outfits, etc.

E. S. NETTLETON,
Supervising Engineer U. S. Irrigation Survey.

Hon. W. M. STEWART,
Chairman Senate Special Committee
on Irrigation and Reclamation of Arid Lands.

Estimate of the cost of the necessary surveys in compliance with the act of October, 1888, for the fiscal year ending June 30, 1891.

California	$50,000	Wyoming	$25,000
Oregon	15,000	Montana	25,000
Washington	15,000	Dakota (North)	10,000
Idaho	30,000	Dakota (South)	10,000
Nevada	30,000	Nebraska	10,000
Utah	40,000	Kansas	10,000
Arizona	20,000	Texas	5,000
New Mexico	50,000		
Colorado	50,000		395,000

GENERAL INSTRUCTIONS FOR HYDROGRAPHERS.

[The following instructions were issued by the chief engineer of the United States Irrigation Survey.]

The duties which devolve upon the hydrographers will be at once of a highly scientific and practical character, and will consist in ascertaining by systematic observations and measurements the values of numerous factors or qualities which must be known in order to fully carry out the purposes of the law, which requires an investigation of the extent to which the arid lands can be redeemed by irrigation. They may be mentioned in the following order:

(1) Measurements of water supply.
(2) Measurements of the loss of water by evaporation.
(3) The investigation of the climatology of the arid region with reference to agriculture by irrigation.
(4) Measurements of sediments transported by streams.
(5) The duty of water.
(6) Collection of general information.

(1) The measurement of water supply will consist primarily in the gauging of streams. For this purpose the methods developed at Embudo will be followed for the present, but with time and experience it is hoped that improvement will come. For this purpose stations will be established on streams to be gauged at points selected, and a systematic record will be kept of the rise and fall of the streams by means of inclined graduated rods, and the stations will be visited by the hydrographers so as to gauge repeatedly at different stations of the water until a sufficient number of stages have been gauged to admit of a formula for the stream and the station. The stream beds will be plotted and the slopes ascertained by leveling. Full records will be kept by the hydrographers of all their gauging work and the results reported monthly to this office.

(2) This evaporation will also be measured by the general methods employed at Embudo. The quantity to be ascertained is the evaporation from water surfaces. Wherever practicable it is desirable to combine station work by placing evaporizaters at the same stations as river gauges; but this must be influenced by considerations of economy and the intelligence of the observers.

(3) The study of the climatology of the West will be mainly the work of the central office, as the data upon which it depends are of regional extent, and most of them are collated by the Signal Service, whose records are accessible only in Washington; but hydrographers are expected to furnish some accessory data, and to cultivate in their divisions the interest of volunteer observers and to promote the organization of meteorological societies. They are cautioned, however, not to duplicate the work of the Signal Service, but to maintain a most cordial and co-operative attitude towards the observers of that bureau and to conform to its methods.

Rain gauges will be placed at stations not occupied by Signal Service observers, and for the present localities at higher altitudes especially need investigating as to the amount of precipitation, and as a general though not invariable rule preference should be given to higher altitudes in choosing rain-gauge stations. It is deemed unadvisable to use the sling psychrometer except in cases where the observer is known to be a man of exceptional intelligence and skilled in the use of meteorological instruments.

(4) The measurements of sediments transported is a subject which must await future development, and no instructions can be given for the present with reference to it.

(5) Care should be taken to ascertain the duty of water in all localities where irrigation is practiced whenever opportunity occurs. The subject should be investigated personally, and too much reliance should not be placed on the mere statements of farmers unsupported by careful measurement. As the duty will vary, much inquiry is necessary to ascertain upon what causes such variations attend. The following factors seem to be of prime importance: (1) Method of flooding lands, (2) climate, (3) character of soil and subsoil, and (4) kind of crop raised.

(6) The central office will be frequently called upon to furnish information not only to Congress but to thousands of individuals throughout the country upon the subject of irrigation. In short, it must constitute itself a bureau of information. The hydrographers are expected to have their eyes open to all facts relating to irrigation and to keep the central office advised of everything of interest.

Reports must be made monthly, embracing a full account of all operations during the month. Records of gaugings, with the plates of the section at the station, and records of soundings and leveling must be kept by the hydrographers and copies of them furnished to this office at such times as will hereafter be stated and upon such forms as shall be prescribed. They will also collate the reports of the rain gauge and other observers and consolidate them, forwarding the consolidated report to this

EQUIVALENTS OF UNITS USED IN MEASURING WATER FOR IRRIGATION PURPOSES.

[Prepared by E. S. Nettleton, supervising engineer U. S. Irrigation Survey.]

UNITED STATES GALLONS.

100 gallons per minute equals—
.44 acre foot in 24 hours.
13½ " feet in 30 days.
40 " " 3 months.
160 " " 1 year.
1 " foot in 55 hours.
.223 " " 1 second.
11⅛ California (miner's) inches.
8⅓ Colorado (miner's) inches.
1 United States gallon equals 231 cubic inches, or 1.748 cubic foot.

CALIFORNIA INCHES.

100 California inches equals—
4 acre feet in 24 hours.
1 " foot in 6 "
120 " feet in 30 days.
360 " " 3 months.
1,440 " " 1 year.
15 gallons per second.
900 " per minute.
77 Colorado inches.
2 cubic feet per second.

COLORADO INCHES.

100 Colorado inches equals—
5⅓ acre feet in 24 hours.
1 " foot in 4.2 "
155 " feet in 1 month.
465 " " 3 months.
1,860 " " 1 year.
19½ gallons per second.
1,170 " per minute.
2.6 cubic feet per second.
130 California inches.

CUBIC FEET.

1 cubic foot per second equals—
2 acre feet in 24 hours.
60 " " 30 days.
180 " " 3 months.
720 " " 1 year.
7.48 gallons per second.
449 " per minute.
50 California inches.
38.4 Colorado inches.

THE SEEPAGE OF WATER.

EXTRACTS FROM THE REPORT OF THE STATE ENGINEER OF COLORADO FOR THE YEARS 1885 AND 1886.

[Filed by E. S. Nettleton.]

Seepage is a subject which is beginning to assume definite importance in connection with the economic use of water for irrigation; but it is only within the last year or two that any observations have been taken to accurately determine the volume in the stream above when canals are taken out and at a given point below. The amount returned to the stream by seepage through the soil was merely a matter of conjecture.

It is a well established fact that before irrigation became so universal in Colorado the water in the streams was greatly decreased in volume as it found its way out upon the plains. This was more particularly observed in the time of low water during the spring and fall season. Those who came up the South Platte Valley a few years ago will remember crossing the river in the eastern part of Weld County on the dry sand.

Within the last ten years at Platteville the river has vanished utterly at times, so that people could cross and recross dry shod. But there has been a change in this respect, and it has evidently been caused by the building of irrigating canals and the distribution and suspension for a time of the water upon and in the uplands adjacent to the streams. Observation and experience prove conclusively that seepage water is an important factor and adds largely to the volume of water flowing in the channel.

The increase in the lower valley of the South Platte has been a matter of notice, and becomes so distinct and certain that new canals have been constructed to take advantage of this interesting and important condition of affairs.

It is well known that the bed of Cherry Creek, once utilized as a thoroughfare for business in the city of Denver, has now a constant stream of water coursing through it, which is unquestionably the resultof seepage from what is commonly known as the High Line Canal of the English company.

In October, 1885, I instituted a series of measurements of seepage water in the Cache la Poudre, in order to obtain some accurate information upon this subject.

Five points of observations were selected, the uppermost being at the measuring flume in the cañon and the lowest at a point east of the town of Greeley, the two points being about thirty-five miles apart. A request was issued to the canal owners to close down the head-gates of all the canals, and so exclude all water; but in consequence of head-gates leaking, it was found necessary to measure the quantity which found its way into each canal and add this amount to that found flowing in the river in order to obtain the total discharge.

The following table shows the results of the measurements made October 12 and 13, 1885:

[Cubic feet per second.]

Places where measurements were taken.	Water in river.	Water diverted from river by canals.	Water in the river at the points measured plus that diverted by canals between those points.	Increase in volume of the river between the points measured.	Increase in river from the cañon to point measured.
First river measurement	127.06				
Pleasant Valley and Lake Canal		1.75			
Larimer County Canal		0.58			
Jackson Ditch		0.27			
Cache la Poudre Ditch		1.00			
Larimer No. 2 Canal		0.54			
New Mercer Canal		0.23			
Fort Collins Canal		1.14			
Second river measurement	134.00		139.47	11.86	11.86
Larimer and Weld Canal		1.73			
Judge Howes' Ditch		2.60			
Josh Ames' Ditch		0.69			
The Lake Canal		1.25			
Cache la Poudre No. 2		3.22			
Third river measurement	150.00		159.47	25.50	37.40
The Whitney Ditch		1.58			
Cache la Poudre No. 3		5.87			
Fourth river measurement	161.86		169.33	19.33	56.69
Ogilvy Ditch		38.96			
Fifth river measurement	153.12		192.07	30.21	86.90

The following table is made up from measurements made of the same river but four years later, or in October, 1889. These last measurements show that the seepage has been increasing since 1885.

Table of measurements of seepage water in the Cache la Poudre River, Larimer and Weld Counties, Colo., October 14 to 17, 1889.

[Cubic feet per second.]

Where measurements were taken.	Water in river.	Water diverted from river by canals.	Water in river at the points measured plus that diverted by canals between those points.	Increase in volume of river between points measured.	Increase in volume of the river from the gauging station at cañon to point where measured.	Increase in volume from gauging station at cañon to point where measured.
						Per cent.
Gauging station at cañon	68.7					
Larimer County Ditch		0.8				
Pleasant Valley and Lake Canal		14.8				
Jackson or Dry Creek Ditch		5.3				
Cache la Poudre Ditch		7.0				
Taylor & Gill Ditch		2.6				
Larimer County Canal, No. 2		12.4				
Fort Collins water-works		0.9				
Fort Collins Canal		0.6				
Larimer and Weld Canal		3.0				
Second river measurement below dam of Larimer and Weld	32.6		80.0	11.3	11.3	16.4
Howe or Pioneer Ditch		1.7				
Josh. Ames Ditch		1.4				
Lake Canal		1.5				
Fort Collins Irrigation Ditch		1.5				
Box Elder Ditch		6.6				
Cache la Poudre Canal		55.2				
Third river measurement below dam of Cache la Poudre Canal	1.5		116.8	36.8	48.1	70.0
Whitney Ditch		2.3				
B. H. Eaton Ditch		0.3				
Union Colony Canal, No. 3		9.8				
Ogilvy Ditch		30.1				
Fourth river measurement below dam of Ogilvy Ditch	3.5		161.3	44.5	92.6	134.7
Fifth river measurement near junction with Platte River	9.9		167.7	6.4	99.0	143.8

Table of measurements of seepage water in the South Platte River, Colorado, October 18 to 25, 1889.

[Cubic feet per second.]

Where measurements were taken.	Water in river.	Water diverted from river by canals.	Inflow from natural tributaries.	Water in river at points measured plus that diverted by canals and minus the inflow from tributaries.	Increase in volume of river between points measured.	Decrease in volume of river between points measured.	Increase in volume of the river from the gauging station at cañon to point where measured.	Increase in volume from gauging station at cañon to point where measured.
								Per ct.
First measurement—Gauging station at cañon	130.8	.....	.....	.....	.....	.....	.....	.....
Little Granger Ditch	.....	4.6	.....	.....	.....	.....	.....	.....
High Line Canal	.....	112.0	.....	.....	.....	.....	.....	.....
Platte Cañon Ditch	.....	0.2	.....	.....	.....	.....	.....	.....
Last Chance Ditch	.....	0.3	.....	.....	.....	.....	.....	.....
Deer Creek	.....	.....	2.6	.....	.....	.....	.....	.....
Nevada Ditch	.....	10.4	.....	.....	.....	.....	.....	.....
City Ditch (Platte Water Company's Canal)	.....	9.8	.....	.....	.....	.....	.....	.....
Plum Creek	.....	.....	3.3	.....	.....	.....	.....	.....
Marcy Gulch	.....	.....	1.4	.....	.....	.....	.....	.....
Lee Gulch	.....	.....	9.3	.....	.....	.....	.....	.....
Brown Ditch	.....	1.5	.....	.....	.....	.....	.....	.....
Second measurement—South Platte River at Littleton	13.4	.....	.....	135.8	5.0	.....	5.0	3.8
Big Dry Creek	.....	.....	3.6	.....	.....	.....	.....	.....
Little Dry Creek	.....	.....	0.9	.....	.....	.....	.....	.....
Bear Creek	.....	.....	3.1	.....	.....	.....	.....	.....
Farmers and Gardeners	.....	0.2	.....	.....	.....	.....	.....	.....
Third measurement—South Platte at Denver	66.0	.....	.....	181.0	45.2	.....	50.2	38.3
Clear Creek	.....	.....	0.6	.....	.....	.....	.....	.....
Fulton Ditch	.....	57.7	.....	.....	.....	.....	.....	.....
Brantner Ditch	.....	16.1	.....	.....	.....	.....	.....	.....
Brighton Ditch	.....	11.9	.....	.....	.....	.....	.....	.....
Fourth measurement—South Platte River at Brighton	7.8	.....	.....	207.9	26.9	.....	77.1	58.9
Lupton Bottom Ditch	.....	6.0	.....	.....	.....	.....	.....	.....
Platteville Ditch	.....	7.9	.....	.....	.....	.....	.....	.....
Ellwood E. Wheeler Ditch	.....	6.4	.....	.....	.....	.....	.....	.....
Big Dry Creek (seepage from Brantner)	.....	3.4	.....	.....	.....	.....	.....	.....
Fifth measurement—South Platte below Ellwood E. Wheeler Ditch	26.1	.....	.....	249.9	42.0	.....	119.1	81.1
Beeman Ditch	.....	.....	.....	.....	.....	.....	.....	.....
Meadow Island Ditch	.....	2.9	.....	.....	.....	.....	.....	.....
Buckers' Ditch	.....	9.0	.....	.....	.....	.....	.....	.....
Farmers' Independent Ditch	.....	18.2	.....	.....	.....	.....	.....	.....
Sixth measurement—South Platte River below Platteville	10.3	.....	.....	264.2	14.3	.....	133.4	101.9
St. Vrain Creek	.....	.....	18.1	.....	.....	.....	.....	.....
Big Bend Ditch	.....	4.2	.....	.....	.....	.....	.....	.....
Union Canal	.....	30.9	.....	.....	.....	.....	.....	.....
Seventh river measurement—South Platte, below dams of Union Canal	6.8	.....	.....	277.7	13.5	.....	146.9	112.3
Big Thompson Creek	.....	.....	6.6	.....	.....	.....	.....	.....
Mayfield Ditch	.....	17.8	.....	.....	.....	.....	.....	.....
Eighth river measurement—South Platte, below dam of Mayfield Ditch	5.2	.....	.....	287.3	9.6	.....	156.5	119.6
Ninth river measurement—South Platte, at head of Latham Ditch	45.7	.....	.....	327.8	40.5	.....	197.0	150.6
Cache la Poudre	.....	.....	14.8	.....	.....	.....	.....	.....
Tenth river measurement—South Platte, at Hoover Ditch	120.1	.....	.....	387.4	59.6	.....	256.6	196.1
Hardin Ditch	.....	1.0	.....	.....	.....	.....	.....	.....
Eleventh river measurement—South Platte, at head of K. and Big Ditch	139.6	.....	.....	407.9	20.5	.....	277.1	211.8
Small ditch (no name)	.....	2.0	.....	.....	.....	.....	.....	.....
Putnam Ditch	.....	30.9	.....	.....	.....	.....	.....	.....
Twelfth river measurement—South Platte	105.8	.....	.....	407.0	.....	0.9	276.2	211.0
Fort Morgan Canal	.....	131.9	.....	.....	.....	.....	.....	.....
Thirteenth river measurement—South Platte, below Fort Morgan Canal	3.6	.....	.....	436.7	29.7	.....	305.9	233.8
Bijou Creek	.....	.....	3.6	.....	.....	.....	.....	.....

Table of measurements of seepage water in the South Platte River, etc.—Continued.

Where measurements were taken.	Water in river.	Water diverted from river by canals.	Inflow from natural tributaries.	Water in river at points measured plus that diverted by canals and minus the inflow from tributaries.	Increase in volume of river between points measured.	Decrease in volume of river between points measured.	Increase in volume of the river from the gauging station at canon to point where measured.	Increase in volume from gauging station at canon to point where measured.
								Per ct.
Fourteenth river measurement—South Platte, at Denel	8.3	.....	.....	437.8	1.1	.....	307.0	234.6
Denel and Snyder Ditch	.....	3.6	.....	.....	.....	.....	.....	.....
Platt and Beaver Canal	.....	25.0	.....	.....	.....	.....	.....	.....
Lower Beaver Ditch	.....	17.5	.....	.....	.....	.....	.....	.....
Beaver Creek	.....	.....	7.0	.....	.....	.....	.....	.....
Smits's or Island Farm Ditch	.....	8.4	.....	.....	.....	.....	.....	.....
Tetsal Ditch	.....	2.3	.....	.....	.....	.....	.....	.....
South Platte Ditch	.....	24.1	.....	.....	.....	.....	.....	.....
Pawnee Ditch	.....	4.4	.....	.....	.....	.....	.....	.....
South Platte, at Merino	8.5	.....	.....	516.4	78.5	.....	385.5	294.7
Schneider Ditch	.....	12.6	.....	.....	.....	.....	.....	.....
Springdale Ditch	.....	3.6	.....	.....	.....	.....	.....	.....
Sterling Ditch No. 1	.....	10.1	.....	.....	.....	.....	.....	.....
Low Line Ditch	.....	1.8	.....	.....	.....	.....	.....	.....
Smith and Henderson	.....	6.8	.....	.....	.....	.....	.....	.....
South Platte, at Sterling	6.4	.....	.....	549.2	32.8	.....	418.3	319.8
Sterling Ditch, No. 2	.....	1.9	.....	.....	.....	.....	.....	.....
Arnette Ditch	.....	8.9	.....	.....	.....	.....	.....	.....
South Platte, near Iliff	.....	.....	.....	553.6	4.4	.....	422.7	323.1

NOTE.—The following are the distances, in an air line, from the different points of measurement:

	Miles.		Miles.
First to second	11½	Ninth to tenth	10
Second to third	11	Tenth to eleventh	4½
Third to fourth	17¾	Eleventh to twelfth	7½
Fourth to fifth	9	Twelfth to thirteenth	4½
Fifth to sixth	7	Thirteenth to fourteenth	7
Sixth to seventh	7½	Fourteenth to fifteenth	18
Seventh to eighth	5	Fifteenth to sixteenth	7¼
Eighth to ninth	2	Sixteenth to seventeenth	4¼

STATEMENT BY CHARLES W. GREENE ON FINANCIAL POLICY.

[Made by request.]

CHICAGO, ILL., *January* 20, 1890.

HON. WM. M. STEWART,
United States Senator, Chairman Special Committee on Irrigation:

DEAR SIR: When in Washington a few days since you asked me to present in writing, for the consideration of the committee, my views in reference to the employment of private capital for the development of irrigation in the arid region.

You suggested that I should wholly discard the idea that the Government shall undertake the construction of any comprehensive and extensive system of reservoirs and canals, and that I should present —

First. The inducements necessary to enlist private capital.

Second. The practical safeguards against the monoply of the public domain by individuals or corporations.

Third. The protection which should be accorded to such investments.

Whatever value may attach to my opinions on these several subjects will be wholly due to the experience gained in almost two years of constant and reasonably successful effort to secure capital for corporate irrigation enterprises, and to the careful study of the subject which has been inseparable to such effort.

As to the first topic. The chief inducement to the investment of capital is the profit which may be directly derived from it. The first question asked is, Will it pay?

Those undertakings, considered as a class, which are proven by experience in different places and under varying conditions to have a reliable earning power, can command almost any sums of money that may be asked, at a rate of interest gauged by the risks incurred.

There must be, however, a public knowledge of such undertakings among the investing classes to command attention. While many investors insist on having personal knowledge of the management, or that it must be under their own eyes, others will take greater risks, provided the margin of profit is sufficient to justify. It is the latter class who will make most of the investments until a better knowledge of irrigation has been disseminated.

To state the difficulties may best suggest the requisites for success. The arid district is localized west of the ninety-eighth meridian, distant from money centers. It is but thinly settled and comparatively little known. There is a wide-spread prejudice, owing to the formerly prevalent idea that it was a "desert," unfit for cultivation and practically worthless.

There is not much of it that is inviting to the casual observer. The natural products are of slow growth; but few of them have any value as food for either man or beast. The tree-growth is shrubby and furnishes no desirable building material and but little fuel. The natural grasses, though nutritious, grow so slowly that as much as 30 acres is required to feed each animal ranging on them. It requires some courage, born of knowledge and experience, to invest money in the reclamation of such lands. Transportation facilities are limited. Settlements are few and far between. There is no inducement for settlement, indeed it is impossible until a water supply is provided.

It follows, then, that a first necessity is to let investors know the truth in regard to these lands. That they are exceptionally fertile. That the application of water makes them wonderfully productive. That the 30 acres which will now support only one animal becomes capable, when a water supply is provided and it is seeded with tame grasses, of feeding from sixty to one hundred animals. That the choicest fruits, and all the cereals, reach the highest perfection upon these apparently barren lands. That agriculture or horticulture becomes there an exact science. That water, sunshine, and soil may be combined by the intelligent cultivator for the production of as certain results as the manufacturer can attain from the combination of labor and the raw material in the various processes of industry.

Your committee has gathered a vast amount of reliable information that proves the value of these lands and the falsity of the popular impression, and which proves, too, the certainty of satisfactory returns for capital judiciously employed. The publication and general distribution of this information will, in my humble opinion, exert a most potent influence to secure the investment of private capital. It is a lack of knowledge which greatly delays such investments.

No greater inducement can possibly be offered than a statement of facts in regard to this region. The term "desert" is a misnomer as applied to such lands as water can be supplied for.

When compared with the granite hills of the East, with a scanty soil and a bleak climate, or even with the prairies of the central West, it has manifold advantages. There is a wealth of natural resources but little comprehended. There is money in the bright warm sunshine; there is money in the water wherever it can be brought and applied to the soil; there is money in the fertile surface soils; there is money in the clays; there is money in the timber; there is money in the vast coal-fields, in the extensive deposits of iron; there is money in the gold mines, in the silver mines, in the copper mines, in the lead mines; there is literally money in the underlying rocks. There is health and comfort in the dry, mild climate, in the mountain air, in the freedom from malaria and pulmonary ailments. These are among the inducements for investing money in irrigation and which will invite settlers to occupy every irrigable acre.

The area under discussion is of vast extent. It includes seventeen degrees of latitude and twenty-four degrees of longitude. The altitude varies from sea-level to about 8,000 feet. The temperature ranges from 40° below zero to 120° in the shade. The products embrace all those of the temperate zone and the subtropical fruits and grasses.

The sources of water supply are from running streams, from springs, and wells, from artesian wells, from tunnels into the mountains, from reservoirs retaining flood waters, etc. The distribution is by gravity through open canals and acequias, through cement and iron pipes at various pressures, or water may be raised or forced by wind, steam, or hydraulic power. The cost of water supply may range from a single dollar per acre to a hundred dollars or even more, and under certain conditions the latter cost may be justified by the returns.

Each locality has its specific advantages and favoring conditions. Experience has proved that irrigation enterprises have been successful in every part of this great area and under all of the varying local circumstances. But very few have been unsuccessful, and those were generally so from faulty management.

They are not all equally profitable. Some localities offer far greater advantages than others, and the most signal successes, as to financial results, have been achieved where the seasons are longest, where the sun shines hottest and most constant, and where vegetable growth is rankest.

The inducements to be presented to investors will necessarily be suggested by the conditions existing in each separate locality.

With a general knowledge of the underlying principles of irrigation, considered as an industry, widely disseminated, each undertaking will commend itself by its own peculiar advantages. These may be a specially fertile soil, a favorable climate, adaptation to particular products, a good local market, the facilities for transportation, cheapness of construction, an active demand for water which makes it command the higher prices, etc.

The security for such investments is exceptional. The increase in value of the land reclaimed is so positive and so rapid, and these values are so substantially based upon land with its earning capacity, that deferred payments and annual charges, as well as reasonable bonded indebtedness, are safe beyond all question. As compared with railroads, water-works, gas-works, or other corporate undertakings where the growth of traffic or patronage is comparatively slow and is contingent upon so many uncertainties, irrigating enterprises increase the values of land reclaimed often many fold within the brief time devoted to construction, and each item added to the income account becomes permanent and practically perpetual at agreed rates.

It will be very difficult to adapt general legislation to all the varied conditions which exist within the arid region of the United States. In Egypt the Nile is the one source of irrigation, and legislation may readily control every detail. In Spain or Italy the area is comparatively small in each, the climate is uniform, and all the conditions are similar, yet in these countries irrigation has presented many difficult problems for solution. It may be here noted that it is everywhere successful and profitable, and when once undertaken is never abandoned.

While the Wright law of California is admirably adapted to the needs of that State, where the lands are nearly all owned by individuals, the titles perfected, and all subject to taxation, where transportation facilities are excellent, and where all industries are well organized and specialized, it is wholly impractical for many localities, and particularly where there are large areas of unoccupied lands. In such localities the investment of capital must precede general settlement. The settler can not occupy or cultivate the land until provision is made for supplying water. The homesteader is not generally wealthy, and most of the localities where it is within the capacity of individual or community effort to secure and distribute water are already occupied and under improvement.

It is those districts where large streams must be diverted, where engineering difficulties are to be overcome, or where the water supply must be stored in expensive reservoirs which are now requiring large sums of money for their development. These are wholly out of reach for the land locator, and all the profit which could be derived under the most favorable circumstances from 100 or 200 acres of land would be small inducement for any man to inaugurate such undertakings. They are clearly beyond the capacity of individuals or communities. The individual can not live there, nor the communities be formed, until the large expenditure has been made and the water supply is actually provided.

Again, the municipal or public corporation system is impractical for such districts, because there is little, if any, taxable property. The homestead is not taxable until final proof is made, and that requires five years of actual residence. Pre-empted land is not taxable until a final receipt is issued, and that may be more than two years after settlement; and so with land taken under the timber-culture law or under the "desert" act, the title remains vested for a longer or shorter time in the Government, and the land is not subject to taxation during that time.

Whatever inducements may be offered to private investors to reclaim and make these lands inhabitable by direct legislation, it appears to me, must be in the way of providing some practical method by which capitalist and settler may co-operate. While the one shall make available a water supply he must be entitled to a fair and reasonable compensation, and the lands deriving a benefit should be held responsible for the payment. This regardless of whether the title remains in the Government after entry or has been perfected by the occupant.

A literal compliance with some of the present laws—which were never designed for the conditions under consideration—would render the construction of irrigation works almost impossible, and of necessity these laws have been construed with some liberality to the settler.

The embarrassments which must attend such legislation are manifold. It is variously estimated that from $80,000,000 to $120,000,000 are already invested in irrigation plants. They have been created under existing statutes, generally State or Territorial enactments. Though any proposed legislation should not be retroactive, any radical change might seriously affect present investments, as these undertakings require years of time for their development, and most of them are just at the beginning. Based upon enactments now in force and calculated upon existing conditions, they may be crippled or destroyed by adverse national legislation. Further investments would certainly be discouraged by injury to present investors.

Popular clamor denounces corporations and demands a scaling of the profits to be allowed capital; but such clamor is not always reasonable or just. The undertakings are too large for single individuals, and the aggregation of capital is only possible under the corporate or company system which has been devised for its concentration and employment and for the determination of personal liability.

Because there have been abuses of corporate powers is no good reason for the denunciation of a system which has accomplished so much that is beneficial.

A law which shall limit the profits of one party where the facilities are specially good and all conditions favorable, would destroy another less fortunately situated.

I shall therefore summarize as to the first topic:

There should be a general dissemination of reliable information to enable investors to judge intelligently as to the merits of the industry as a whole and as to particular localities. To this end the hydrographic and topographical surveys should be hastened. This is clearly within the province of the Government to provide. They need not be accurate and complete surveys, but rather preliminary, only presenting such general data as will determine the relative location of suitable dam sites, sufficient storage capacity and available arable lands, and as to what reservations are actually necessary. The extent of drainage area and average rain-fall should also be determined. There are not so many of these favorable locations as may be supposed. Indeed, they are comparatively few.

The area to be reclaimed is of such vast extent and there is such a variety of soil, climate, productions, of transportation facilities, of water supply and distribution, that national legislation may easily prove prejudicial.

The land laws should permit of co-operation between capital and settler. There should be positive assurance that the Government will not compete with nor embarrass private undertakings, though it may adopt all proper safeguards against the abuse of granted privileges.

With national legislation to protect the public land while providing for its occupancy; to determine as to suitable dam and reservoir sites; to prevent the occupancy of sites adapted to reclaiming and utilizing a large area by parties who only improve a fraction of it; to definitely determine the rights of appropriation of water limited to its use only; to grant the use of designated reservoir sites and right of way for canals and ditches on public lands, I submit that the legislation suited to each locality for the inducement and protection of investors can be properly and safely intrusted to the States and Territories.

The second topic: What are the practical safeguards against the monopoly of the public domain by individuals or corporations?

So much more is heard of the abuses of granted privileges than of the benefits derived that it is not unnatural if it creates an unfavorable opinion as to public honesty.

Yet it is quite safe to assert that the great mass of investors are really desirous of acting within the law. Obedience to and regard for the law is a necessity to the stability of investments. It is a small minority who are disposed to take advantage of their associates or of the Government. With the experience of the past as a guide it ought surely to be possible to guard against the schemes of the evil-minded without unduly restricting the operations of those who in good faith are willing to aid in creating wealth from the vast undeveloped resources of the region in question by the use of their capital.

There are four prominent methods under existing laws of acquiring title to the public lands.

The homestead law provides for a long bona fide residence and the payment of only nominal fees to acquire title. As I have before suggested, a homestead settlement can not very well precede a permanent water supply, and is only possible where the annual rain-fall will permit of some cultivation or will produce partial crops. It is, therefore, impracticable to adapt the present law to many large areas which it is possible and desirable to irrigate.

The pre-emption law requires a shorter term of actual residence on the land, but exacts $1.25 an acre in payment for it. This law has been taken advantage of and abused more than any other. If repealed as to the irrigable region it could probably be substituted by a better enactment.

The timber-culture law is objectionable in many respects, yet nowhere is there greater need to encourage the growth of trees for timber and fuel. If such encour-

agement could be provided for in some other way, or if it should be required of canal-builders, perhaps, as a condition to the granting right of way to plant trees along the main canals and principal laterals and on the margin of reservoirs, it would be of inestimable advantage to the public welfare. It would fully compensate the expense to the builders or owners of the canals by direct benefits.

The desert act has many good features and some bad ones. It gives inducement for the reclamation of the land by allowing the acquirement of a full section to each individual. It does not require residence either before or after the water is provided. The entryman may not be a resident either of the State or Territory. It does not stipulate as to what use shall be made of the land or how much shall be put under cultivation. It only requires that permanent water shall be carried to each 40 acres, and evidently assumes that when such expense has been incurred the self-interest of the entryman will prompt him to cultivate it. Under this law great abuses have been perpetrated, and yet it has some commendable features.

Can not a law be framed that will contain the good features of all these several laws and be the only one under which these lands may be acquired?

It may provide:

(1) For a reasonable limit of area.

(2) Prohibiting more than one entry to each individual, and defining the qualifications of an entryman.

(3) That the entryman may mortgage it to secure a water supply to a certain limit and to insure its maintenance.

(4) For a time limit within which the water supply may be secured.

(5) For actual residence and cultivation after water is obtained.

(6) For the perfection of title when certain improvements have been made or when a stated proportion has been brought under cultivation.

(7) For encouragement to tree-planting, not by the acre of solid growth, but by the number of thrifty trees, permitting the planting along ditches or fence rows and to include either fruit or forest trees.

(8) Severe penalties for the violation of its provisions.

As to the limit of area, it must in great measure depend upon the class and locality of the lands. While 5 acres of orange orchard, or other semi-tropical fruits, may afford a handsome income, 5 acres of land only adapted to grain or a single crop of grass would not be worth having. Whether the lands shall be classified, and who shall be authorized to make the classification, will require careful consideration.

The importance of rapid settlement and improvement of the reclaimed lands, and the advantage of having it occupied by the greatest number of occupants, is so great to a company providing water supply that it almost insures the exertion of every energy to that end. If, then, there shall be a limitation put upon the acquirement of extensive areas to be held for speculative purposes without improvement the returns to capital will be made dependent upon legitimate efforts.

A combination of the irrigable and pastoral lands has been strongly urged by Major Powell. Whether it can be practically accomplished throughout the entire region and under all circumstances is a question for very careful consideration. A limited area immediately adjoining a small tract of irrigated land could have no great value. Take the gramma grass districts as an instance. After each rain-fall the stem of this grass freshens and renews its growth. As the surface moisture is evaporated it dries and growth ceases until the rain falls again. It is equally nutritious, dry or green. It requires three years for a growth of 6 to 12 inches. If cut or fed close it may be months before it will again furnish pasturage. Under the present system of range feeding cattle can feed at any time over a range of 5 miles or more from permanent streams or springs. As soon, however, as a heavy rain or snow fall permits them to leave such permanent water they travel for long distances upon the plateaus or into the mountains. When one section is covered with snow they drift to another, it may be one side of a mountain where the snow melts soonest, so that localities many miles from permanent water are now utilized for pasturage. That these cattle must have access to the permanent water goes without saying, and the fencing in of such waters can not be permitted. If they are prevented from reaching the river they must have access to the canals or reservoirs. But if the pasturage shall be confined to the tract immediately adjacent to the irrigated lands many districts of plateau and mountain will be wholly worthless.

The third topic: What protection shall be accorded to such investments:

(1) A definite determination as to the rights which may be acquired in the use of water.

(2) Legal protection against subsequent locators who may seek to divert water supply where provision has already been made for its distribution for such reasonable time as will permit the settlement and improvement of the lands.

(3) A lien against the lands benefited to secure the payment of a just compensation for constructing the works and for their maintenance and for the use of the capital

invested, such lien only to apply as against the private ownership as acquired under the laws.

(4) Protection against malicious injury to the works and against the improper use or waste of water by the occupant of the land or others.

(5) Power to adopt and enforce such rules and regulations for the distribution of water as may be necessary to conserve and to facilitate its economic use.

The subject is very broad and of great importance, and I appreciate that in the brief time at my disposal and under the pressure of business engagements I have not been able to do it full justice.

REPORT BY E. M. McCLELLAN, C. E., ON ELKO COUNTY, NEV.*

Elko County, situated in the northeastern part of Nevada, is 155 miles in width, east and west, and 120 miles in length, containing 16,670 square miles of land.

About 30 miles south of the north boundary, extending across the county from east to west, is the water-shed, separating the waters of the Columbia and Snake Rivers from those of the great basin.

This water-shed is composed of several different parallel mountain ranges which trend north and south, having an elevation of 8,000 to 10,000 feet above the sea-level.

In many places the valleys between these ranges have such an even slope both ways from their highest part that it is only by close observation a person can determine when they have crossed the water-shed. At other points the ranges are connected by cross mountains, nearly as high as the main mountain.

On the north side of this water-shed are six main streams, viz: Goose Creek, in the east, Salmon River, Bruneau River, and the east, middle, and west forks of the Owyhee River. In the northwest corner of the county, lying between the east and west forks of the Owyhee River, is the Owyhee Desert, containing over 1,000,000 acres, 750,000 acres of which is fine agricultural land.

Four of the rivers now flow north, viz, the Salmon, Bruneau, and east and middle Forks of the Owyhee, which show distinct traces of having once discharged their waters in the opposite direction, and in the valleys at their heads can to-day be traced the shore-line of old lakes. At that time also the water-shed was farther north than now, and its course northeast and southwest. Subsequently the vast lava field, which covers Oregon, Washington, and Idaho, flowed up to and in some places over the divide. The consequent settling of the earth's crust beneath the weight of the lava caused an elevation of the country a few miles away from the edge; and also the convulsion which broke apart the mountain near by, and which are shown to-day by the deep, narrow cañons through which the rivers flow.

Upon leaving these cañons the rivers have worn away the lava to a great depth, and now flow across the desert in precipitous gorges from 200 to 3,000 feet in depth. Where the mountains end and the lava field commences, the rivers are very near the level of the desert and can be readily carried over it. And in each of these cañons, which are not over 100 feet wide at the bottom, dams can be placed turning the valleys again into lakes, and the water, now running to the ocean, will be utilized in reclaiming land, which is the richest and most productive in the world, but, as it now lies, is worthless.

As most of the agricultural lands lying below the old lake beds on the Salmon and Bruneau Rivers and Goose Creek are in Idaho I will not report on them, but will mention a small lake bed, near the head of the Salmon (No. 18), which can be re-flooded and 20,000 acres reclaimed in this State, and one on Goose Creek (No. 19) which will irrigate 10,000 acres.

Upon the east fork of the Owyhee are two reservoir sites, Nos. 16 and 17, on appended plat.

No. 17 is at the upper end of the ancient lake bed and can be utilized in irrigating 4,000 acres of land below it, which will not be covered, by a reservoir 100 feet high at No. 16.

No. 16 will flood about 10,000 acres at the lower end of the old lake bed and store sufficient water to irrigate 150,000 acres of land. It has 220 square miles of natural water-shed, some of the mountains being 10,000 feet high.

No. 15 is an old lake bed, now called Bull Run Basin, and is the finest small reservoir site in the country. It has about 50 miles of water-shed, is surmounted by high mountains, and water can be stored for 50,000 acres.

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* This report did not reach the committee in season to be inserted in the third volume of testimony.

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No. 14 is in the southern part of the State; same lake bed as 15, the mountain having been broken open in two places, but the site for a reservoir is not good. It is separated from 15 by a ridge 100 feet high.

No. 13 is the old lake bed near the head of the main Owyhee, and has a drainage of 270 square miles. The storage capacity and water supply is amply sufficient for 250,000 acres.

The Little Owyhee, heading west of Elko County and flowing across the northwest corner, has a small lake bed near its head, not shown on the accompanying map. The waters stored in these reservoirs, Nos. 13, 14, 15, and 16 and on the Little Owyhee, can by canals be conducted upon the lava field at the highest places and conveyed over all the land which water can be collected for. The necessary canals leading out from the cañons and constructed along the base of the mountains would also gather all the water coming from the mountains in the small streams which flow down. The early spring flow from these streams alone will irrigate at least 50,000 acres during the flow, which lasts till July.

Heading in the water-shed and flowing south into the Great Basin are a large number of fine streams, the largest of which flow through ancient lake beds, which can be converted into reservoirs. Commencing on the west, the first one is the Little Humboldt River, which rises upon the southern crest of the lava belt; flows north 18 miles, then west and southwest. There are no lake beds along its course until after it enters Humboldt County.

Rock Creek flows south through two old lake beds, each of which will be easily flooded. The first, No. 12, at the lower end of Squaw Valley (the present name of the old lake bed), has a drainage of 400 square miles. There are only about 10,000 acres of agricultural land in Elko County below this reservoir site. The second, No. 11, 12 miles below the first, in Rock Creek Basin, and partly outside this county, has an additional drainage of 200 square miles.

About 200,000 acres of good agricultural land lies below these two in Eureka, Lander, and Humboldt Counties, a part of which can be reclaimed by these reservoirs.

No. 9 is another lake bed, situated just outside of this county. It is not as good a reservoir site as any of those so far named, but has a fine water-shed of 250 square miles on Maggie Creek. About 10,000 acres can be reclaimed by this.

No. 10, on Susie Creek, is a small reservoir point; has a water-shed of 50 square miles, with 3,000 acres of good agricultural land below.

The north fork of the Humboldt, with its tributaries, flows through five old lake beds. Nos. 2, 4, 5, and 6 are comparatively small, and will flood about 2,000 acres with dams 30 feet high. No. 3 is the largest and most important in the county south of the water-shed. The old lake bed covers nearly 10 square miles, drains 750 square miles of territory, and will irrigate 100,000 acres of land which lies below it.

No. 7, near the head of Mary's River, on Hanks Creek, is also an important reservoir site. It has 50 square miles' drainage of mountains 9,000 feet high, and nearly 200,000 acres fine agricultural land below it.

No. 8, at the head of Bishop Creek, is a second-class reservoir site, with a drainage of 75 square miles.

No. 1 is the only lake bed that can be used on the south side of the Humboldt River, and a very important one, as into it can be put the drainage of 700 square miles, covering the highest mountain range in the State of Nevada (the Ruby Mountains, which are 13,000 feet high). A dam here 100 feet high would cover 10 square miles, but it would take one at least 200 feet high to hold all the water now going to waste. There are at least 1,000,000 acres of agricultural land below in the Humboldt Valley.

These lake beds, from Nos. 1 to 12 inclusive, lie in the Humboldt Basin. In addition to these, which are away from the main river, there are three places in this county where the river has broken through mountain ranges—at A1, A2, and A3—where are fine sites for large reservoirs but impracticable on account of the railroad and towns in the valley. They also mark the sites of old lakes which were several hundred feet in depth.

A1, at the junction of the north fork with the Humboldt River, is the largest. A2, below the mouth of the south fork, is second in size. A3, in the western part of the county, at the mouth of Maggie Creek, is third in importance. The break through the mountains below A3 forms the Palisades, noted as the finest bit of scenery along the overland railroad.

Below each of these reservoir sites is sufficient land to be irrigated with all the water that can be stored in it.

The Humboldt River is the most important river in the Great Basin, having nearly 1,500 miles of water channel. The entire water-shed of this river lies in Elko County, except two tributaries of the Little Humboldt in the northern part of Humboldt County, and Reese River, in Lander County, which flows north through the central part of the State.

The river in its course southwest, after leaving Elko County, flows across one other larger lake bed than any of those above, and breaks through another chain of

mountains at Iron Point, between Battle Mountain and Winnemucca. Battle Mountain is built within this lake bed, and contains the only artesian wells that have been sunk in the eastern part of the State. Reese River enters the Humboldt Valley at this point.

Through Elko County the Humboldt River bottom is about a mile wide. On each side are bluffs from 50 to 100 feet high, and extending back from these bluffs to the foot of the mountains on both sides lie table lands, upon which the few farmers in our county are located, and where all crops raised in the temperate regions can be grown and harvested with far less work than in the countries not irrigated. At the present date the farms are located along the small streams where they come from the mountains, and where the only work necessary for reclaiming the land was to clear off the brush at a cost of $2 an acre and run a plow furrow from the creek upon it.

Only one reservoir has been built in the county. It is located in Squaw Valley, in the western part of the county, and a canal in connection with the reservoir has reclaimed 5,000 acres. The company expect to irrigate as much more by it as soon as the land can be cleared off. This land without the water was worthless, now it is worth $100 an acre. The cost of constructing the dam and canal was $200,000. Cost of 5,000 acres of land cleared and planted was $25,000, which leaves a gain of $275,000.

The cost of the next 5,000 acres will be only $25,000 which will net the company owning it $475,000.

The reservoir site, utilized by them, is poorer than any which I have mentioned as yet, being the only one which the company could utilize for their land. There are a large number of reservoir sites throughout the county as good as the one utilized in Squaw Valley.

In the northeast corner of the county the water-shed has turned north to within 12 miles of the north boundary, and on the south slope is the headwaters of Thousand Spring Creek. The north branch, called Rock Creek, heads here 25 miles west of the Utah line and flows south 20 miles. The South Fork, or main Thousand Spring Creek, heads 35 miles south and 25 miles west of the head of Rock Creek, flowing northeasterly to the junction.

Just below the junction the mountain has been broken through, and above it is the reservoir site, marked No. 20 on the appended map. These creeks drain 450 square miles of water-shed, one-third of which is mountain land. Twelve miles below this, one, at No. 21, is another lake bed, which can be utilized, but the opening where a dam would be built is nearly 300 feet wide. It has 125 miles of additional water-shed. Below these two reservoir sites is 125,000 acres of fine valley land.

The waters of Thousand Spring Creek and all east of the Ruby range of mountains belong to the eastern part of the Great Basin in which Salt Lake is situated. In the southeastern part of the county the mountain ranges are lower than elsewhere and the precipitation of moisture far less. The prevailing storms are all brought from the Japan current in the Pacific Ocean, northwest of us, and the water-shed on the north and Ruby Mountains on the west catch most of the moisture as the clouds go over them.

There are two ranges of mountains in this section, with valleys between, which have no outlet and were lake beds at some period of greater precipitation than now.

Between the Ruby range and the first range east the valley is divided into two parts. The southern part, lying close to the Ruby Mountains, is called Ruby Valley. It is 5 miles wide at the lower end and 12 at the upper. At the south are two lakes—Ruby and Franklin. The Ruby range is low at the south, furnishing comparatively little water, and Ruby Lake is fed by numerous springs which overflow from the artesian belt beneath, created by the ancient lake. Franklin Lake, just north, and about the same level as Ruby lake, is supplied from the surface streams which flow into it and Franklin River.

Ruby Valley is 50 miles long. Northeast of Ruby Valley is the northern part of the main valley, which is subdivided into two valleys, called Clover Valley and Independence Valley.

Clover Valley lies on the east of the mountains, which is here generally called Clover Mountains. The valley is 20 miles long and 10 miles wide. East of Clover Valley is Independence Valley, 40 miles long and 10 wide.

These two valleys once formed a lake of greater extent, but have now less precipitation of moisture than Ruby Valley.

Just south of Independence Valley is Spruce Mountain, which has an elevation of 10,000 feet but is only 3 miles long on the summit. East of the south end of Ruby Valley are the north ends of Long and Butte Valleys; across the mountains lies Steptoe Valley. It is divided into two parts, the northern part lying in this county and being 60 miles long and an average width of 10 miles; it is called Goshute Valley. The ancient lake bed in this valley is more extensive than in the valleys west of it, but at the present day the precipitation of moisture is far less. All of these valleys show the presence of artesian belts beneath, but no wells have ever been sunk and it is not known what supply they will furnish.

There are no good reservoir sites in this section of the county, and although there are over 1,000,000 acres of fine agricultaral land in these valleys, not over 200,000 acres of this can be irrigated without a large expenditure for storage. The Ruby and Clover range have sufficient snow and rain-fall to irrigate all the land in the valleys if it was stored.

The reservoir sites thus far described are the largest and best in the county, will need an average expenditure of $100,000 each, and the work can only be done by the Government or capitalists. Twenty of the twenty-one mentioned have an outlet where the dam would be placed less than 100 feet wide, and a dam 100 feet high would not be over 700 feet long at the top.

The bottom and sides of the cañons are, in all cases, solid rock, and stone for building can be quarried on the spot. The land to be irrigated below them still belongs to the Government. Nearly all the land in this county taken up is on the low bottoms along the rivers and streams that were natural meadows, where the ground is too damp and cold to raise anything but grass.

Owing to our poor transportation facilities and an unjust discrimination against the whole State by the only through line of railroad in it, the farmers have been only able to raise cattle for the markets abroad. The consequence is that in selecting land the first necessity for the settler was to find a piece of meadow where he could at once raise hay for his stock. Then if by a little work he could clear off and cultivate a small garden to raise enough vegetables for his own use he had to be contented.

Before the railroad was built connecting the mining town of Eureka, in Eureka County, with the Central Pacific Railroad the people had a good market for their produce, and farms were taken up and vegetables and cereals grown for that market along the slope of the Ruby Mountains. Upon the construction of the railroad and a combination of the two roads produce of all kinds were shipped from California and the East cheaper than the farmers could land it in town. For a number of years grain was shipped from California to Eureka for $10 a ton; at the same time if a Nevada farmer living near the railroad wished to ship his grain to Eureka he would have to pay $30 a ton. On all other farm produce the same unjust discrimination is used.

This has nothing to do with the amount of agricultural lands and reservoir sites in our State, I know, but it accounts almost entirely for the lack of advancement we have made. Neither capital nor settlers are attracted to a place where they know exorbitant rates will be charged them for everything that can not be raised but must be shipped in; where, when anything is raised, the rates for importing the same thing is lowered till it can be sold within a few miles at a less price than it can be raised and landed to the market for; and where, when a market for the produce is found away from home, the rates are raised till it will not pay to ship it. These are the actual facts in this State, and because of this the people have been confined to the raising of cattle and horses, which could be sent to market without depending upon the railroad.

The interstate law has helped us some, but there still remains high rates which only a competing line of railroad will overcome.

A close estimate of the land in this county shows that we have nearly 2,500,000 acres of No. 1 agricultural land and about 1,500,000 acres of this can be reclaimed by a proper storage and distribution of water. In doing this the reservoirs so far mentioned only form the principal points for storage. There are hundreds of small reservoir points where a small expenditure of capital and work will create a storage of waste waters capable of irrigating from 100 to 10,000 acres of land each.

In calculating the agricultural acres I have only put in my estimate those lands in the county where it appears the best results could be had. I have left out nearly 1,000,000 acres which have a rich soil but which lie in small tracts not easily reclaimed compared with the rest. When this State has the population which its vast mineral wealth and unrivaled climate will some day bring to it, most of this land will also be utilized.

As I have stated before most of the lands taken up lie along the river and creek bottoms and are too cold and damp to raise anything but hay. Along the Ruby Mountains is the largest exception to this rule, and it is here that most of our farmers have settled. Here at an elevation of nearly 6,000 feet above the sea-level can be raised all the products of the temperate regions, including grapes, peaches, cherries, apples, and small fruits as well as all the vegetables and cereals.

The climate is so healthy that there are only four doctors in the whole county, and most of the cases they have are caused by accident and not from disease.

Of this 2,500,000 acres of good land, only 90,000 acres is under irrigation to-day, and 60,000 of this is natural meadow, leaving only 30,000 acres actually farmed. All lands that are to be reclaimed are farming lands, being dry and warmer than the bottoms. A very liberal estimate to be placed upon the cost per acre for storage of the water and canals for conveying it upon the lands would not be over $20. The cost of clearing it off ready for cultivation would not be over $5 per acre more, making a total cost of $25.

In the northwestern part of the United States, along the Pacific coast, where immigration is now directed, the actual cost of clearing the land and getting it ready for cultivation is $135 per acre. The land is no richer, the climate far inferior, and the amount of work to harvest a crop nearly double what it is in this State.

There is also in all non-irrigating regions the liability every few years of drought with consequent loss of crops or excessive moisture with equally bad results. Here the farmer can tell before planting, even without storage, exactly how many acres can be irrigated each year, and, supplying the growing crops himself with just the amount of water needed for each product, he never misses a harvest, and the produce of his fields and orchards is fully equal and in many cases superior to those of non-irrigating countries.

The traveler crossing our State sees only the worst sections of the eastern part. The line of the railroad along the river bottom under the bluffs is 50 feet or more in elevation.

Looking from the car window he can see in the distance the mountains covered with perpetual snow, and can imagine that there must be streams flowing from them, but he does not see the miles of rich table lands intervening, across which flows from April to June sufficient water to convert every acre of it into productive farms if held in reservoirs until needed.

No measurement of the annual flow of water in the numerous streams in the county of Elko is known, but the farmers who have been in the country the longest state that they are positive the quantity of water flowing to waste every year is amply sufficient to irrigate every acre of agricultural land in the county. If this be true, it would bring 3,500,000 acres under cultivation instead of 1,500,000 as I have estimated.

The agricultural land and the water to irrigate it lie in close proximity in this northern part of the State. The only thing necessary to create a fertile and populous county out of the seeming desert, is wise legislation founded upon a just appreciation of the needs of an irrigation district.

All enactments of our law-makers, since the organization of the United States, have been founded upon the English common law, acknowledged to be the best in the world, and as long as we had only a country to make laws for which did not need irrigation the English riparian act was the one needed for that country. But now we have a vast empire of arid lands for which an entirely different code of laws is required, and to successfully meet these requirements it is absolutely necessary to frame laws of a character wholly unprovided for by English common law. To do this it is not necessary that experimental enactments be passed as though irrigation was a new thing in the world.

The experimental stages of law-making for the successful reclamation of arid lands have been passed through by other governments, both in the new world and the old, and all we have to do is to adopt the best of these, or compile a code of laws from the best parts of all or some of them with the very slight changes which might be necessary to their introduction into a free country.

The main point upon which the successful solving of the irrigation problem depends is the absolute ownership and control by each State government of all waters, storage points, and right of way for main feeding and distributing canals. The State could then construct the canals and reservoirs and rent the water (as done by other governments) at rates determined by the cost of constructing and keeping in repairs the necessary works.

No time should be lost by the Government in securing all the water and storage points in the arid regions. The history of other irrigating communities should be sufficient for us to be assured that only evil will befall any section of our country where one of the main elements of life is the property of any individual or corporation and can not be controlled by the people.

Our agricultural lands lie at a general elevation of 5,000 to 6,000 feet above the sea-level. Our mountain ranges have varied elevations of from 7,000 to 13,000 feet in height. Very few observations have been taken of the amount of rain and snow fall at different elevations in the country, and at only one place have we any data for a series of ten years past.

At this place (Camp Halleck), situated at an elevation of nearly 6,000 feet, the main precipitation for the ten years was 10.5 inches annually. That is the general average of precipitation also over a large part of the agricultural lands of the same general elevation, but it nearly all falls in the winter and spring and has mostly disappeared before the irrigation season is over. This amount of precipitation is greater than in many places in the United States where irrigation is unknown.

The precipitation in the mountains can only be estimated, but it can not be less than three times that of the valleys.

STATEMENT OF ARNOLD HAGUE, GEOLOGIST, U. S. GEOLOGICAL SURVEY, IN RELATION TO THE NATIONAL YELLOWSTONE PARK AS A WATER RESERVATION.

In the organic act of 1872, establishing the Yellowstone Park, Congress declared that the reservation was "dedicated and set apart as a public park or pleasure ground for the benefit and enjoyment of the people." The wisdom and foresight of those who at that time urged the withdrawal from settlement of this tract of land from the public domain has never been questioned.

The necessity for the protection of the geysers and hot springs and other unrivaled scientific curiosities of the region, the importance of utilizing the park as a game reservation for the larger Rocky Mountain animals rapidly becoming extinct with the settlement of the country, and the natural advantages of the place as a sanitarium and health resort, have since been recognized by the steadily increasing crowds of visitors who annually visit the place.

From these æsthetic points of view alone the value of the Yellowstone Park to the nation have amply repaid for all cost of maintenance. Its advantages to the nation in the future has scarcely begun to be realized even by those most familiar with its charms and natural advantages. Notwithstanding all that may be urged in favor of a liberal maintenance of the Park based upon sentimental considerations, the most forcible argument for its preservation is an economic one far outweighing all others in benefits to the people.

In my opinion the object of first importance in maintaining the Park is the conservation and regulation of its water supply. By the natural configuration of the country the Park is singularly adapted as a catchment basin for the storage of water. It is doubtful if any region of the same extent in the arid regions of the Rocky Mountains offers so many favorable conditions for receiving, storing, and distributing through a few main drainage channels so large an amount of water.

The Park is situated in the extreme northwest corner of Wyoming, and covers an area approximately 50 by 40 miles. The central portion of the Park is an elevated volcanic plateau between 7,000 and 8,500 feet above sea-level, with a mean altitude of 8,000 feet. The surface of the plateau is diversified by undulating basins of varied outline cut by numerous deep cañons and gorges. Strictly speaking, it is not a plateau in the popular acceptation of the word; at least it is by no means a level plain, but a rugged country presenting bold escarpments, the edges of mesa-like ridges. Rising above this plateau on the south, east, north, and northwest occur mountain ranges whose culminating peaks tower from 2,000 to 4,000 feet above the inclosed table-land.

The Gallatin Range shuts in the Park on the north and northwest. Spurs and outlying ridges of the Gallatin connect it with the Snowy Range, an elevated mountain mass which bounds the Park on the north and pours a large share of its water into the Yellowstone River. The Absaroka Range borders the Park along the entire eastern side and presents for more than 80 miles an unbroken barrier to all western progress. It is an exceptionally rugged region with volcanic peaks and table-topped masses rising from 10,000 to 11,000 feet in height. Only a few adventurous hunters and mountaineers cross the range by one or two dangerous, precipitous trails, known to but few. The early trappers found it a forbidding land; prospectors who followed them, a barren one. The Absaroka Range, however, furnishes one priceless treasure: from its western slope it sends numerous torrents into the Park, many of them running directly into Yellowstone Lake. On the east side of the range an equally large water supply make up the Stinking Water and Clark's Fork, which ultimately flow into the Yellowstone River. The Absaroka Range is intimately connected with the Wind River Range, which shuts in the plateau on the south. To the westward, and separated only by the broad valley of the Upper Snake, lie the Teton Mountains, whose northern outlying spurs project into the Park. On the southwest side of the Park is situated the Madison Plateau, which stretches northward until it abuts against the southern end of the Gallatin.

From this incomplete sketch it will be seen that the Park country, although a high table-land, stands relatively low to the rugged mountains which surround it on all sides. From this outer rim of mountains innumerable streams pour their waters into the Park.

Across the plateau from the southeast to the northwest, but with a very irregular course, runs the Continental Divide separating the waters of the Atlantic from those of the Pacific. On both sides of the Continental Divide and within a few miles of the line, lie a number of large bodies of water which form so characteristic a feature in the scenery of the plateau that the region has received the appellation of the lake country of the Park. Hundreds of smaller lakes lie dotted over the surface, filling

irregular depressions in the lava flows or occupying shallow basins scooped out by glacial ice. Many of these lesser lakes are found as natural reservoirs higher up in the mountains. In addition to these are found numerous ponds, marshes, and meadows everywhere scattered over the country. So numerous are they that the water held by them adds a very considerable amount to the total water supply. Two rivers, the Yellowstone and Snake, receive the greater part of this water, the former draining more than one-half the area of the Park and the latter the entire western side of the Continental Divide. Falls River, a very considerable stream in the southwest corner of the Park, empties into Henry's Fork before its waters join the main Snake River. On the north side of the Divide both the Madison and Gallatin drain large areas of the Park, the former, running westward, cuts through the Madison Plateau, while the Gallatin, although receiving none of its water from the Park plateau, still carries off a large amount of water precipitated upon the reservation. Both these latter streams unite with the Jefferson in Montana to form the Missouri.

Let us examine a little more closely into this water supply. I can not do better than to quote from an article on the physical features of the Park which I published not long since.

"Yellowstone Lake, the great reservoir for the river which gives its name to the Park, is a body of water of great beauty, measuring 20 miles in length, with a breadth across its greatest expanse of 15 miles. It has a very irregular outline, with an indented shore of nearly 100 miles, and an area of 140 square miles. Not only is the Yellowstone by many times the largest lake in North America at so high an elevation above sea-level (7,741 feet), but it ranks among the first in the world at high altitudes. Upon the western side of the Divide, less than 6 miles from the Yellowstone, and separated from it by a ridge not more than 200 feet in height, lie Shoshone and Lewis Lakes; the former with an area of 12 square miles, and the latter 4½ square miles. Heart Lake, at the eastern base of Mount Sheridan, measures 3 square miles. These three smaller reservoirs pour their waters into the Snake, which also finds its source near the southeast corner of the Park.

"In the autumn of 1886, with a view of obtaining some data upon the amount of discharge, the largest bodies of water were accurately measured. Not only was the time selected the driest period of the year, but all lakes and streams stood at a lower level than at any time during the previous five years. Yellowstone Lake stood 20 inches below the high-water mark of early summer. The measurements may be said, therefore, to have been taken at the minimum discharge. Measured just below the outlet of the lake the discharge of the Yellowstone River was found to be 1,525 cubic feet per second, or, in other words, 34,000,000 imperial gallons per hour. The out-flows from Shoshone, Lewis, and Heart Lakes combined yielded 104 cubic feet per second. The Lamar, Firehole, Gibbon, and Madison Rivers were gauged, and careful estimates made of the Gallatin and Falls Rivers, based upon the size and flow of the streams and the area of the country drained. According to estimates of Dr. William Hallock, of the U. S. Geological Survey, who kindly undertook the gauging of the streams, it was found that the minimum discharge was equal to 1 cubic foot per second per square mile over an area somewhat more than 4,000 square miles, and that the amount of water running into the Park and leaving it through the five main drainage channels would make a river 5 feet deep and 190 feet wide, with a current of 3 miles per hour. While this may not indicate a large supply as compared with certain highly favored areas, yet it is for the arid region of the West an exceptional amount."

While there are many conditions governing both the amount of snow and rain fall in the far West, two important factors are found in the Park region which influence in a large measure the precipitation of moisture. These are the great elevation of the culminating peaks surrounding the Park, and the exceptional broad mountain mass. From Madison Valley eastward across the Park and the Absaroka Range the country attains an elevation unsurpassed by any area of equal extent in the northern Rocky Mountains. For 90 miles in an east and west line the country rises in a solid block far above the adjacent country, admirably situated to act as a condenser for the moisture-laden clouds. Meteorological records taken for a number of years show a climatic condition unlike that observed elsewhere in the Rocky Mountains, the amount of snow and rain fall being higher and the mean annual temperature lower. Rain-storms occur frequently throughout the summer, while snow is quite likely to fall any time between September and May. In an arid region and one of unequally distributed rain-fall, forests and moisture maintain reciprocal relations. The abundant precipitation over the Park exerts a favorable influence upon forest growth, 84 per cent. of the area being timber-covered. This forest in turn protects the snows and marshes from the intense heat of the sun and the dry westerly winds. By means of this protection the deep snows of winter lie upon the plateau well into midsummer, while at still higher altitudes in sheltered places it remains throughout the year, slowly supplying the springs and streams.

By its topographical structure the Park is designed by nature as a reservoir to collect an exceptional water supply. By its geological structure it is well adapted to store this water, both on the surface and in the deeply buried rocks. From beneath the lavas of the plateau numerous streams and underground springs pour their waters into the lakes and out upon the land surfaces.

For these reasons the present area should be enlarged to the east and south so as to take in a dense forest region useless for agricultural purposes and destitute of mining resources, but embracing a rough, mountainous country abounding in streams—the real sources and feeders of Snake River, Yellowstone Lake and River. The area proposed to be added to the Park would extend the boundaries about 25 miles to the eastward and 9 miles to the southward of the present ill-defined limits which were established at a time when the region had been but little explored. The proper control and distribution of the water is a necessity to the people of Montana, Dakota, Wyoming, and Idaho. The protection of the forests, game, and marvels of the reservation should be the desire of every one looking to the welfare of the country. The interests of the Park should be zealously guarded by the nation.

REPORTS ON IRRIGATION

FROM

CONSULS OF THE UNITED STATES.

CORRESPONDENCE WITH STATE DEPARTMENT.

UNITED STATES SENATE,
Washington, D. C., April 23, 1889.

SIR: Referring to your letter of the 2d instant, in which you state that "our consuls will be instructed to prepare reports covering such phases of the subject (namely, irrigation) as you may be good enough to intimate," I inclose herewith a draught of a letter which if you will have sent to our consuls in the countries mentioned in the inclosed memorandum where irrigation is practiced, will greatly oblige the Senate Committee on Irrigation and Reclamation of Arid Lands.

Please forward all reports received by you to Mr. R. J. Hinton, Engineer, U. S. Geological Survey, Washington City.

Yours, respectfully,

WM. M. STEWART,
Chairman Committee on Irrigation, etc.

The SECRETARY OF STATE.

DRAUGHT OF LETTER IN REGARD TO IRRIGATION TO BE SENT TO CONSULS.

WASHINGTON, D. C., *April* 23, 1889.

The questions connected with irrigation and the reclamation thereby of arid lands are now attracting public attention. Congress has recently made appropriations for surveys of reservoir sites, ditches, canals, etc., and the United States Senate has created a special committee to thoroughly investigate the general questions involved. The Department, in response to an inquiry from the special committee, desires to aid in its investigations, and therefore requests as early as practicable a report on the subject of irrigation as practiced in the country in which you are stationed. Your inquiries should be directed in the main to the following points:

(1) Areas of land under irrigation; compare with the non-irrigable and cultivable areas when possible. Also quantity and quality of crops grown.

(2) Sources of water supply, whether from rivers, streams, springs, lakes, wells, reservoirs, catchment basins, or tanks, etc.

(3) Character of works used for storage and distribution of water. Forward published reports, if obtainable, in regard to any important irrigation and storage works.

(4) The system of water distribution, whether governed by laws, rules and regulations, or customs. Give duty of water per acre, *i. e.*, the amount used per acre and per season, the cost or rental to user;

tenure of ownership of water, and whether the same be public or private, national or community.

(5) Character of climate in irrigated region and nature of soil, annual rain-fall or other precipitation.

(6) Antiquity or otherwise of irrigation systems within the section treated of, and whether the same are maintained at public or private expense.

The Department desires to obtain maps and any publications obtainable bearing upon this subject for the use of the Senate committee.

The committee states that it desires to place itself in communication with competent experts and authorities on irrigation. These investigations should be conducted diligently, and reports made as early as possible.

MEMORANDUM FOR DISTRIBUTION.

All Asiatic countries: Egypt, Tripoli, Tunis, Morocco, Algiers, Senegambia, Orange Free State, Colonies of Cape of Good Hope and Natal, Madagascar, etc. Also, Madeira, the Azores and other islands, the Australian Colonies, Hawaii, South and Central American Republics, the Empire of Brazil, Mexico, and European Colonies of South America. The principal countries of Europe in which irrigation is practiced are France, Italy, Spain, Portugal, Holland, Turkey, Greece, Austria; also Russia in Asia.

MEXICO.

REPORT BY UNITED STATES CONSUL JOHN WOESSNER, OF SALTILLO, ON IRRIGATION IN COAHUILA, MEXICO.

A part of this section of this large and rich State is irrigated from springs which generally rise in the mountains; the water is carried in many cases and often many miles from these springs to level, fertile land by means of narrow ditches. Other parts of this State, the lands can not now be irrigated on account of no water, and the total absence of the necessary implements for boring and the proper practical labor to accomplish the required result. Where there are springs the water should be carried through iron tubes; farther away from here, where there are no springs, but "haciendas" of importance, the artesian well, it seems to me, is what is needed. I would advise manufacturers in the United States who desire to build up a trade of this kind to do so with a direct representative who speaks the language, establishing an office centrally located in the Republic, where attention may be given to the wants and demands of such a trade.

Water is worth a great deal more than land in this country, and the right to use it is fixed by laws. Much good land is not used because of lack of water, and to depend on rain in some parts is too much of a risk. With a good water supply much of the rich soil of this State would produce abundantly of nearly all kinds of products, which at present are not enough to support the population.

There are very few windmills used at present in this State, though I think they might be successfully used, for the reason that good winds blow nearly all the year. There is considerable water-power unused, which, according to law, can be acquired by denouncement. If a spring of water rises in the property of any one, the owner of the property

also owns the spring. Rivers are owned and controlled by the State through which they pass. Rights and privileges to public waters are sold by the State.

The system of water distribution is as follows and is generally acquired by purchase: A stream of permanent water is called thirty days of water and the owner may sell the right to any one to use this water for any length of time; say, for example, one day in every month, which is called one day of water, worth very often as high as $1,000 per day. It is an understood right between all land owners that parties owning any right or privilege in the water can pass same to their land through the lands of adjacent owners by means of narrow ditches. This system often causes many difficulties, particularly when the owner of a day or two of water dies and leaves some fifteen or twenty heirs, each of whom receives his share in hours, being an equal division under the same right of the day or two of water inherited. The formation of artificial lakes has already awakened attention, and a foreign company of capitalists agitates at present the question of making a lake with the waters of the Rio Grande, to be used for industrial and agricultural purposes. This project, however, involves difficulties, arising from its international character.

REPORT BY U. S. CONSUL A. WILLARD.

UNITED STATES CONSULATE,
Guaymas, Mexico, August 14, 1889.

Up to the present time the lands cultivated in Sonora (this consular district) are confined to the bottom or valley lands on the small streams and rivers.

For the purpose of irrigating said lands dams of simple construction of stone and earth, or brush and earth, are erected on the sides or in the streams, and ditches are dug to convey the water to the lands cultivated. These dams, as a rule, require repairs and some reconstruction each year.

The ditches require cleaning and repairing yearly, but are not expensive to maintain.

REPORT BY U. S. CONSUL-GENERAL C. C. MORE, CITY OF MEXICO, ON IRRIGATION IN MEXICO.

The system of irrigation has become very generally practiced in various portions of this republic, having been in vogue more or less ever since the days of the conquest of the country by the Spaniards in 1521.

It may be stated as a general proposition that the natural supply of water in Mexico is very limited as compared with that of other countries. The traveler in this republic notices the great scarcity of rivers, running streams, lakes, and springs. In the mountains of the country many small streams take their rise, but soon after reaching the plains they become absorbed in the sandy soil and sink into the ground. Again, in Mexico during the rainy season there is a great abundance of water (said rainy season may be stated, in a general way, as extending from June 1 to October 1), but for the remainder of the year the rain-fall is very scant, water becomes very scarce, and the whole country becomes very dry, except in the regions along the sea-board (the

Pacific Ocean, the Gulf of California, the Gulf of Mexico, etc.), in which localities the dews are very heavy and refreshing showers much more frequent than in the upland regions.

I will now take up the six points of interrogatory mentioned in your circular, and incorporate in my replies the information obtained from the said department of public works and from other sources:

(1) "Areas of land under irrigation; compare with the non-irrigable and cultivable areas when possible, and quantity and quality of crops grown."

Answer. The department aforesaid assured me that they had no statistics upon which to frame an answer to the first part of this question, and that it would take months to collect the information in proper shape.

The principal crops grown here with the assistance of irrigation are sugar, coffee, corn, wheat, oats, barley, beans, cotton, and tobacco; also oranges, bananas, and other fruits. Without irrigation, except near the coast, the yield would be very meager; with irrigation said crops are excellent, and will compare favorably with those of other countries, especially when consideration is had of the primitive agricultural implements used and the inefficient cultivation as contrasted with that practiced in the United States, England, France, and Germany.

(2) "Sources of water supply, whether from rivers, streams, springs, lakes, wells, reservoirs, catchment basins, or tanks, etc."

Answer. The water supply for irrigating purposes is drawn principally from rivers, streams, and natural lakes. In some instances bold springs gush from the earth and furnish a constant, never varying supply for irrigation of thousands of acres, as in the case of "Atlacomulco," in the State of Morelos, a large, beautiful "hacienda," or plantation, at one time owned and operated by Cortez, the Spanish conqueror, and still belonging to decendants; on the hacienda of "Coakinstla," one of the finest sugar plantations in Mexico, near the city of Cantla. Sometimes also large dams of solid masonry are constructed at great expense, which, however, form large reservoirs of water during the rainy season, and which during the remainder of the year furnish the necessary supply for irrigation. Artesian wells supply some of the water used for irrigation; also wells from which the water is raised and poured into the irrigating canals by means of windmill pumps and buckets attached to an "endless chain," which are kept in motion by mule or horse power.

(3) "Character of works used for storage and distribution of water. Forward published reports, if obtainable, in regard to any important irrigation and storage works."

Answer. The works used for storage and distribution of water consist of dams constructed so as to elevate the level of the water in streams and rivers where they can not be tapped by the aqueducts and irrigation canals at sufficient elevation to reach the destined fields of cultivation; also large reservoirs are formed, as above stated, through the instrumentality of massive dams, generally of stone masonry, the water being collected during the rainy season and held for use when needed.

(4) "The system of water distribution, whether governed by laws, rules and regulations, or customs. Give duty of water per acre, *i. e.* the amount used per acre and per season, the cost of rental to user, tenure of ownership of water, and whether the same be public or private, national or community.

Answer. As a part answer to the fourth interrogatary, the department of public works handed me a copy of the decree of June 5, 1888, which I herewith have the honor to inclose, accompanied by a translation of the same into English.

Each State of the Republic has its separate laws and regulations regarding the distribution of water. The duty ot water per acre, or the amount used per season per acre, varies according to the quality of the soil, climate, and plants under cultivation. Moreover, the cost of water is generally included in the rental paid for the lands, which varies exceedingly in different places, according to the peculiar circumstance attending each locality.

The ownership of the water is both public and private, but generally the latter, as the water privileges, being considered of quite as much value as the land itself, have in many instances been transferred or transmitted by inheritance along with the title to the land.

(5) "Character of climate in irrigated region and nature of soil; annual rain-fall or other precipitation."

Answer. The climate of the irrigated region in this country corresponds to the climate of the different States of the Republic, as in all of them there exist irrigated lands, with this general statement, however, that on and near the sea-coast the climate is much warmer and the rain-fall much greater than on the table-land and in the mountain districts.

As a further answer to this question, the said department of public works furnished me with a copy of the geographical, statistical, and descriptive study of Mexico by A. Garcia Cubas, special attention being called to the seventh and eighth chapters, relating respectively to hydrography and agriculture.

The nature of the soil embraces every variety known to the country, from the light, sandy soil of the table-lands to the rich, dark alluvial of the valleys and the fertile, black loam of "the tierras calientes"—the hot countries.

In regard to the annual rain-fall, said department handed me the tenth number of the monthly bulletin of the meteorological, magnetic, central observatory of Mexico in which is published a report on the rain-fall in different parts of the Republic, running through a number of years; also a table containing a comparative résumé on the subject for the years *et seq.* to 1888, and both of which, in deference to the request in said circular, I have the honor to herewith transmit—

(6) Antiquity, or otherwise, of irrigation systems within the section of, and whether the same are maintained at public or private expense.

Answer. The antiquity of the various systems of irrigation in Mexico varies with the different localities, they having been constructed and put into operation not simultaneously, but at different epochs, as the different sections became more or less cultivated by intelligent labor and the necessity of irrigation became apparent. As a general proposition, however, it may be stated that said systems date all the way from the early part of the sixteenth century when the Spaniards took possession of the country, introducing their splendid system of irrigation as rapidly as they began the cultivation of the various localities.

The department of public works further assures me that none of said irrigation works are maintained by public funds.

[Translation.]

[Department of public works, colonization, industry, and commerce. Third section.]

The President of the Republic has thought fit to direct to me the following decree:

Porfirio Diaz, constitutional President of the United States of Mexico, to its inhabitants makes known:

That the Congress of the Union has decreed the following:

ARTICLE 1. There shall be considered as general, public highways, besides the inland roads, railways, etc., to the effect of section 22, article 72 of the constitution, the following:

The territorial seas, marshes, and lagoons situated on the sea-coast. Canals constructed by the Government or by means of public money. Interior lakes and rivers, if navigable. Whatsoever lakes and rivers situated and serving as boundary lines between this Republic and other foreign nations or between two States.

ARTICLE 2. The Federal Executive has the power and right to look after the aforenamed public roadways and to regulate the private and public use thereof, according to the following basis:

A. The towns situated on the sea-shore or banks of a river shall have the gratuitous use of the water necessary for all domestic purposes of its inhabitants.

B. There shall be respected and confirmed the rights of private individuals relating to the use and profit of rivers, lakes, and canals, providing that said rights consist in lawful titles or civil prescription exceeding ten years.

C. The concession or attestation of rights or titles to private parties on the lakes, rivers, and canals relating to the present law, can only be made by the department of public works, excepting the case where said concession shall change or threaten to change the course of the rivers or canals aforenamed, or should deprive of the use of their waters the inhabitants living down the stream.

D. The rights of fishing and pearl-diving on the territorial seas and the uses and profits of marshes and lagoons situated on the sea-shore or national vacant lands, shall be regulated specially by the executive power.

ARTICLE 3. All transgressions of the law comprised in the common jurisdiction committed on interior lakes, canals, or rivers, as well as the controversies that may arise between private individuals, relative to obeying the statutes issued by the department of public works, shall be submitted to the competent local jurisdiction.

MEXICO, *May* 28, 1888.

Miguel Castellanos Sanches, senator president; Luis C. Cariel, deputy president; Guillermo de Landa y Escandon, senator secretary; A. Riba y Echeverria, deputy secretary.

Therefore, I order it shall be printed, published, and circulated, and that due compliance shall be given it.

Signed in the palace of the executive power of the Union, in the City of Mexico, on this 5th day of June, 1888, Profirio Diaz. For General Carlos Pacheco, secretary of State, and the department of public works, colonization, industry, and commerce. I recommend it to you for your knowledge and corresponding efforts.

Liberty and constitution.

Mexico, June 5, 1888.

PACHECO.

CUBA.

REPORT FROM OTTO E. REIMER, U. S. CONSUL, ON IRRIGATION IN THE CONSULAR DISTRICT OF SANTIAGO DE CUBA.

Before answering the questions propounded in your circular of May 2 it would be well to enumerate in brief the reasons which render irrigation in this consular district almost unnecessary. I say "almost unnecessary" because all the crops, such as sugar, cocoa, coffee, plantains, and other crops of minor importance, are dependent on the changes of rainy and dry seasons in this tropical climate. This consular district is well watered by rivers and small streams which irrigate the rich and deep alluvial soil under cultivation. The largest river, the Canto, which finds its source in the Sierras del Cobre, a mountain range to the westward of this city, and after a tortuous and winding course during which

it receives various tributaries, empties into the sea 14 miles north of the town of Manzanillo. This river, choked up at its mouth by drift-wood and sand bars, is about 180 miles long, of which 60 are navigable. Captain General Salamanca has caused studies to be made in view of forming a plan to make the mouth of the river navigable, thus opening a water-course which traverses some of the most fertile districts of this province. The Canto, with its tributaries, constitutes the water system of the south coast of this province. Between the Capes Maisi and Cruz the coast line is very mountainous and only small streams find their way to the sea.

The north coast is full of larger and smaller rivers which find their way into the numerous and large bays. Notably the Mayari, Naranjo, etc. So artificial irrigation has as yet not become a necessity excepting, to my knowledge, only in one instance. Messrs. Brooks & Co., an English firm here, owning a sugar estate on the bay of Guantanamo and called "Los Canos," have been compelled, owing to the curious fact that although sufficient rains fall near and around the estate very little falls on its territory, to introduce an artificial system of irrigation. This system of open ditches irrigates about 10 caballerias (333⅓ acres) of cane fields, and as just commenced I cannot give you the results. The water for this system is procured from the Guantanamo River, which is dammed above the area irrigated and the water distributed by a system of canals. The system was instituted after the necessary permission was obtained from the Spanish Government; is a private enterprise, and pays neither rental nor taxes.

The amount of water used per acre depends on the rain-falls of the rainy season and can not be estimated, as the work has just commenced. The character of the climate is tropical and the annual rain-fall, in the absence of all scientific observation, I would estimate at 45 inches.

CENTRAL AMERICA.

REPORT OF U. S. CONSUL-GENERAL JAMES P. HOSMER, GUATEMALA, ON IRRIGATION THEREIN.

In reply I beg respectfully to state that there is no system of water distribution for arid lands in Guatemala.

The practice of irrigation, in the very limited extent to which it obtains, is that of ordinary ditches fed from the nearest water source.

REPORT OF U. S. CONSUL CHARLES H. WILLS, OF MANAGUA, NICARAGUA, ON IRRIGATION.

There is not, nor has there ever been, as far as I can learn, any system whatever of irrigation.

Wear Nandaime, a small Indian town in the department of Rivas, three cacao (chocolate) estates are partially flooded in a primitive way by their owners from small rivers or streams being dammed to cause the water to flow over the plantations, which are below the streams. No system is practiced.

SOUTH AMERICA.

REPORT OF WINFIELD S. BIRD, U. S. CONSUL, LA GUAYRA, ON IRRIGATION IN VENEZUELA.

The subject of irrigation, to which the attention of consular officers is directed by circular instruction from the Department of State, dated May 2, 1889, is one upon which very meager information can be furnished from Venezuela; for although, in a crude way, irrigation is practiced to some extent, yet there are no available statistics to offer in reference to the areas of land under irrigation, and no means of comparing these with the non-irrigable and cultivable lands. Of the small area of cultivated lands in this consular district, exclusive of those planted in coffee, perhaps the greatest part is devoted to sugar-cane; and, from personal observation, it would appear that the crop generally needs more cultivation and irrigation than is usually given it.

The small streams coming down from the mountains form the only supply of water for the purposes of irrigation, and in a tropical climate like this the volume of water is so often reduced during the long and hot summer season that the supply proves inadequate, and consequently the crops suffer to a greater or less extent. The present season has proved quite disastrous in this respect, so much so that crude sugar, usually sold at 10 cents per pound, is now worth 25 cents per pound. The importation of cane products being prohibited by law, it seems that the use of sugar and its compounds, so general in this climate, must be greatly curtailed, and, to many of the poorer classes, entirely cut off.

The character of the works used for the storage and distribution of water are of the simplest description and consist of ordinary dams and trenches. There are no irrigation and storage works of any importance, every process of this nature being conducted upon the most inexpensive and antiquated plan. It is no doubt true that even the Chinese are, in this respect, far in advance of these people in the various appliances and processes for irrigation; and it is equally true that if a more careful and provident system were adopted, much of the water that now goes to waste might be utilized for the reclamation of arid unproductive lands.

The system of water distribution is governed, according to the best obtainable information, by custom only, although there are some statutes in reference to it that, by common consent, have fallen into disuse. The unwritten law is that each person shall have the right to water on a stated day for a certain length of time, when he must close his flood-gate and again await his turn. Under such an arrangement, therefore, it is evident that the amount of water used per acre and per season and the tenure of ownership, etc., can not be intelligently stated.

Everything connected with the subject of irrigation in Venezuela is of such primitive character that it can be of no special interest in the elucidation of plans and processes for use in the United States. No maps nor publications with any reference to it can be obtained or even heard of, and it appears that the subject has never received the slightest degree of the attention that its importance to the agricultural interests of the country so seriously demands

REPORT OF O. McGARR, U. S. CONSUL-GENERAL, GUAYAQUIL, ON IRRIGATION IN ECUADOR.

(1) A very small quantity of land is under irrigation in Ecuador, not the thousandth part of the cultivable land. No grain crops are grown on irrigated land, which is used only for pasturage and for raising alfalfa in small quantities. An infinitesimal part of the arid region, which is extensive in northern Ecuador, is under irrigation.

(2) Small rivers, mountain streams, and springs are the source of the water supply. There are no basins, reservoirs, or tanks used.

(3) There are no works constructed for the storage of water. Its distribution is by ditches. No reports on the subject have been published in this country.

(4) The system of water distribution is governed by custom, except in the few instances where water is carried over the land of adjoining proprietors. In such cases the law regulates and defines the rights and duties of the owner of the easement and of the servient estate. I have no means of ascertaining the amount of water used per acre or per season. It is not measured and it is not rented. The water used for purposes of irrigation belongs to the individual land owner using it. There is no national, municipal, or community ownership.

(5) The climate is that of the winter-Andean region with an average maximum temperature, with shade, of 62 to 68 degrees, the average minimum being about 54 degrees. In some localities the soil is a sandy loam and in others a dark, heavy clay, and very deep. The rains are ordinarily confined to the months between the middle of December and the first of June, and are quite copious in most seasons. I can not state annual rain-fall.

(6) Under the Spanish rule there was something of an irrigation system, regulated by laws, and at the time of the Conquest there was a better and more extensive system than has existed since. That now in use is maintained entirely at private expense.

REPORT FROM J. GRIERSON, U. S. CONSUL, COQUIMBO, ON IRRIGATION IN THE PROVINCE OF COQUIMBO, CHILI.

This province is in a very backward and primitive state as regards cultivation and irrigation, on account of the country being very barren and mountainous, the only cultivation being along the valleys running down between the mountains which convey the snow-water from the Cordilleras. Hay and barley are the principal productions, the former, when green, being eaten on the ground by cattle.

Water is supplied by canals or large ditches cut at different places from the rivers of snow-water, as mentioned above. Each canal, from its leaving the river until it reaches the sea, belongs to the owners of land along the upper part of which the canal flows.

No works are made for stowage of water. When the river is full the sluice doors to the canals are open all the time, and water is supplied in abundance; but in years when there is little snow on the mountains, and consequently the river low, the sluices are opened, as arranged by the canal committee.

Each canal has a president and a committee, elected from the cursors, who superintend repairs, allowance of water, etc. The value of a farm depends on the number of inches belonging to it; each proprietor of land can buy or sell any or all the number of inches of sluice he has a right to draw from the canal, each inch being worth about $3,000 (gold)

and is the same as tangible property. A sluice-wall 15 to 20 inches makes a good farm worth about $3,000 to $4,000 yearly.

The climate is good and very mild. Up the valleys grapes, oranges, and pears grow well, and by irrigation five crops of hay may be cut yearly. From 1872 to 1880 the rain-fall was only $3\frac{1}{5}$ inches per year; latterly, with intermissions, it has been about 7 inches yearly.

The rivers are, of course, under Government control, but the canals are private property and from time immemorial have been superintended and kept in order by their owners. Every town, however, is entitled to a proper proportion of water.

REPORT FROM W. T. WALTHALL, U. S. CONSUL, DEMERARA, ON IRRIGATION AND DRAINAGE IN BRITISH GUIANA.

No systematic irrigation exists in this colony. The need of it is felt when the dry seasons are protracted beyond their ordinary limits, but in such cases the only methods employed to water the crops are of the simplest and most primitive description—by manual labor, without the aid of machinery of any sort. The system of drainage, however, and of the employment of artificial water-ways for the transportation of produce and plantation supplies is elaborate, costly, and extensive. Although not strictly pertinent to the information sought by the Department, the subject is somewhat akin, and a brief account of it may not be irrelevant.

In order to understand the conditions, it must be borne in mind that the rich agricultural region of the colony consists in general of the low-lands adjacent to the sea-coast and the tidal parts of the larger rivers. These lands are several feet below the level of the highest tides, for which reason it is necessary to protect them from overflow by a continuous line of embankments, or "sea-dams" as they are termed.

This cultivable region extends back from the beach and the banks of the lower rivers to a distance varying (by a rough estimate) from 2 to 5 or 6 miles, when it meets what is termed, in the language of the colony—perhaps not very correctly—"the savanna" or "bush" lands. This is a belt of country between the rich coast lands and the hills and forests of the interior, slightly more elevated than the former but lower than the latter, partly open and partly covered with trees, vines, and shrubs, but everywhere abounding in swamps, ponds, and creeks of fresh water.

The estates of the colony are laid off on the plan adopted by the original Dutch settlers and still existing in its main features. They are divided by parallel lines, approximately perpendicular to the line of coast, and forming long, narrow, and somewhat irregular quadrilaterals, which would be parallelograms but for the sinuosities and irregularities of the coast line. The unit of measurment of distance is the Rhynland rood, still in habitual use, of 12 feet 4 inches. The original width of each grant was 100 roods, or nearly a quarter of a mile, and the length or depth from the sea-dam 750 roods, or about $1\frac{3}{4}$ miles. Such is at this time actually the extent, inland, of the only lands owned in fee-simple, though many of the estates have been extended toward the "savanna," or including parts of it, by grants of possession and occupancy at the pleasure of the Crown, supposed to be practically equivalent to ownership. Many of the original estates have also been united and some of them divided, though the regular parallelism of their side boundaries is still maintained.

In order to protect these estates from overflow in the rainy seasons by the waters of the swamps, ponds, and streams of the "savanna,"

"back-dams" are erected in the rear of the cultivated area. On the lines of division between the estates canals or trenches are dug for drainage, the earth thrown out from these constituting material for embankments, known as "side-line dams," which also serve as road-beds for walking or riding. Smaller cross-drains connect with these side-line trenches.

Besides the trenches for drainage, another system of trenches or canals is employed for the internal navigation of the estate. For this purpose a canal is generally dug through the estate, the excavated earth forming alongside of it an embankment known as the "middle walk." Cross-canals extend transversely from this toward the boundaries of the estate but stopping short of them, so as not to communicate with the side-line or drainage trenches, the terminus of the navigation cross-canal forming a sort of *cul-de-sac*. These canals are used for the transportation, by flat-bottomed barges or "punts," of the crops, fertilizers, etc., in one direction or the other.

These canals are supplied with fresh water from the swamps, creeks, ponds, and in some cases artificial reservoirs of the "savanna," the water being admitted and the supply regulated by means of water-gates, or "kokers" as they are termed, in the back-dams. Stronger and more elaborate kokers are employed in the sea-dams, which are opened at low tide to permit the discharge of the drainage and other fresh water, and closed at high tide to hinder the influx of the sea-water.

The coast lands of the colony consist of a stiff clay, interspersed with veins of sand and covered with a superficial layer of vegetable mold or "pegass." The clay being impervious to the percolation of water is very favorable to rapid drainage from the surface.

The chief staple is sugar, though there are some cocoa-nut plantations, and in certain parts of the colony large estates, or "cattle-farms," are devoted to pasturage.

I have spoken of artificial reservoirs. The advantages of these in regulating the varying supply of fresh water during the wet and the dry seasons are obvious. Besides those already existing, others are projected on a still larger scale.

The cost of the works required for drainage and the supply of water to the towns, villages, and estates is assessed on the proprietors and others interested, though they are controlled and regulated by the Government. The money is frequently advanced by the Government with the understanding that it is to be repaid by taxes on the property for the benefit of which it is expended. This, of course, does not apply to the works undertaken by proprietors for the special benefit of individual estates. In some cases, also, participation in the burdens and benefits of public or corporate enterprises is to some extent optional with the individuals interested.

The climate of the colony is torrid, but remarkably uniform, the extremes of temperature being about 73 and 90 degrees Fahr. The average is about 81 degrees. The average annual rain-fall is estimated at about 100 inches.

REPORT FROM E. L. BAKER, U. S. CONSUL, BUENOS AYRES, ON IRRIGATION IN THE ARGENTINE REPUBLIC.

I am in receipt of the circular of the Department of State of the 2d of May last, stating that the question of reclaiming the arid lands of the United States is now attracting the attention of our Government, and instructing me, in aid of its inquiries, to report on the subject of irrigation in the Argentine Republic, and especially directing my at

tention to the areas of land under irrigation, the sources of the water supply, the nature of the works, the system of distribution, the character of the climate, the annual rain-fall, the antiquity of the works, etc.

ANTIQUITY OF IRRIGATION IN SOUTH AMERICA.

In regard to antiquity, I have to say that the artificial watering of the earth to increase its fruitfulness is of so remote an origin in South America that its history is quite unknown. It has been generally assumed that the practice had its beginning in the Orient; and we know that in the days of the patriarchs various contrivances for flooding the fields and meadows were in general use. It was not, however, until the end of the seventeenth century that water meadows were constructed in Europe upon anything like a scientific system; and only towards the end of the eighteenth century that any great improvement took place in this branch of agriculture. In South America, on the contrary, it is evident that a scientific system of flooding, which consisted in spreading a sheet of water over cultivated fields in such a manner that it could be readily withdrawn was not only practiced by the aborigines of the country from the most remote periods, but that it was done with an amount of precision and knowledge which even to this day are matter of wonder to those who inspect the remains of their works.

It seems hardly possible that the natives of Peru and Bolivia, and of the eastern slopes of the Andes, which now constitute a part of the Argentine Republic, could have acquired their skill from the nations of antiquity beyond the Atlantic; and hence we are at a loss to understand how such a people, without a long-previous civilization, far in advance of their condition when their Spanish conquerors arrived, could not merely have solved the problem of the artificial watering of the land to increase its productiveness, but constructed aqueducts and reservoirs to that end, on such an immense scale and in such an enduring manner that they have defied the changes and vicissitudes of unnumbered centuries. When they were built we do not know; but their remains abundantly prove that the inhabitants from an unknown date were well versed in many of the ways and means of civilized life; that they pursued husbandry and practiced agriculture on scientific principles, and that, in defiance of the general absence of rain, they succeeded in providing bountiful harvests even on the precipitous sides of the sterile sierras. The historian of the conquest of the country refers to the knowledge of agriculture possessed by the primitive inhabitants and the wonderful works of irrigation constructed by them in such a manner as to prompt me to make a quotation from his pages. He says of the "ancient works":

> Much of the country suffered for want of water, as little or no rain fell, and the few streams in their short and hurried course from the mountains exerted only a very limited influence on the wide extent of territory. The soil, it is true, was for the most part sandy and sterile, but many places were capable of being reclaimed, and indeed needed only to be properly irrigated to be susceptible of extraordinary production. To these spots water was conveyed by means of canals and subterraneous aqueducts executed on a noble scale. They consisted of large slabs of freestone nicely fitted together without cement, and discharged a volume of water sufficient, by means of latent ducts or sluices, to moisten the lands in their lower level through which they passed. Some of these aqueducts were of great length. One that traversed the district of Condesuyu measured between 400 and 500 miles. They were brought from some lake or natural reservoir in the heart of the mountains, and were fed at intervals by other basins, which lay in their route along the slopes of the sierra. In their descent a passage was sometimes opened through rocks, and this without the aid of iron tools; impracticable mountains were to be turned; rivers and marshes to

be crossed; in short, the same obstacles were to be encountered as in the construction of their mighty roads.

Most of these beneficent works of the incas were suffered to go to decay by their Spanish conquerors. In some spots the waters are still left to flow in their silent, subterraneous channels, whose windings and whose sources have been alike unexplored. Others, though partially dilapidated and closed up with rubbish and the rank vegetation of the soil, still betray their course by occasional patches of fertility. Such are the remains in the valley of Nasca, a fruitful spot that lies between long tracts of desert, where the ancient water-courses of the incas, measuring 4 or 5 feet in depth by 3 in width and formed of large blocks of uncemented masonry, are conducted from an unknown distance.

The greatest care was taken that every occupant of the land through which these streams passed should enjoy the benefit of them. The quantity of water allotted to each was prescribed by law, and the royal overseers superintended the distribution, and saw that it was faithfully applied to the irrigation of the ground. (Prescott's Conquest of Peru, Vol. I, pp. 131–133.)

Patches of these prehistoric works are still to be found in the provinces of Mendoza, San Juan, and the upper Andine provinces of the Argentine Republic, though the ravages of time and the reckless indifference of the first conquerors of the country have in nearly every instance reduced them to ruins.

IRRIGATION AFTER THE CONQUEST.

If, however, the early Spanish colonists were more intent in their search for gold than in that for the riches which agriculture produces, their descendants in those far Andine provinces slowly awakened to the fact that the only return they would ever be able to get for their labor would be from the cultivation of the soil. While throughout the pampas, consisting of the provinces of Buenos Ayres, Santa Fé, and Entre Rios, the people followed the lazy but lucrative employment of breeding cattle to the entire neglect or abandonment of agriculture, which exacted more hard labor and patience than they were inclined to give it, in the far interior provinces, where, owing to the lack of seasonable rains, there was a general absence of pasturage and cattle were unable to feed themselves, the colonists were compelled from necessity to direct themselves to agriculture, but they did it in such a way that compared with the science displayed by the aborigines the cultivation of the soil actually retrograded. Mr. Nap, in his work on the Argentine Republic, says:

While the country was a Spanish colony, agriculture was neglected to the greatest degree, even in those districts where it had previously been the principal occupation of the primitive inhabitants.

Indeed the conquistadores of the Argentine Republic found there an indigenous population more numerous than themselves, which, if it was not quite so far advanced in agriculture as the ancient inhabitants of Peru, had adopted many of their ways and usages in regard to irrigation, and were especially experienced in the cultivation of the soil. The Spaniards, failing in their search for gold, were compelled to accommodate themselves to the circumstances which surrounded them. Thus they adopted the customs and habits of life of the natives, and partially undertook agriculture; and though it was not vigorously exploited, yet it became of a certain importance.

Thus, when the towns increased and a greater consumption was required, the pampa provinces were provided with cereals from the provinces of the interior. For example, the far distant province of San Juan, as late as the year 1860, still sent flour to the Atlantic coast; and notwithstanding the high cost of the transportation by land it was yet able to compete with that of North America, and even surpass it in quality.

But owing to droughts and the constant want of timely rains, it was absolutely necessary to secure the necessary moisture by the artificial means of irrigation; and yet it is unfortunately the case that in some of those provinces so little attention was paid to the proper systems of irrigation that these means for watering the fields were actually worse under the Spanish dominion than they were before the period of the conquest.

Since the organization of the Argentine Republic as an independent government, while agriculture was scarcely thought of in the pampa provinces until recent years, the cultivation of the soil has continued to be the principal occupation of the inhabitants of the interior provinces. And it is only in those of Mendoza, San Juan, Catamarca, Santiago del Estero, Tucuman, Salta, and Jujing that any attention is at all paid to the subject of irrigation. Indeed, but for such artificial means, owing to the lack of rains, it would be impossible to raise crops at all in any of them.

CLIMATE AND RAIN-FALLS OF THE INTERIOR PROVINCES.

In regard to the character of the climate it will be borne in mind that the Argentine Republic extends from 56 to 20 degrees south latitude, and consequently in such a wide zone is subject to a very great variety of climatic conditions. While the far northern provinces have quite a tropical temperature, and the Cuyo provinces have a temperate climate, those portions of the country which extend towards the Straits of Magellan have about six months of quite severe winter. I may also add that the mountain ranges gradually rising on the west to the regions of perpetual snow have great effects upon the temperature even in regions of the same latitude. On this account, in compliance with the instructions of your circular, I shall have to give the character of the climate and the quantity of rain-fall for the different interior provinces separately, beginning with—

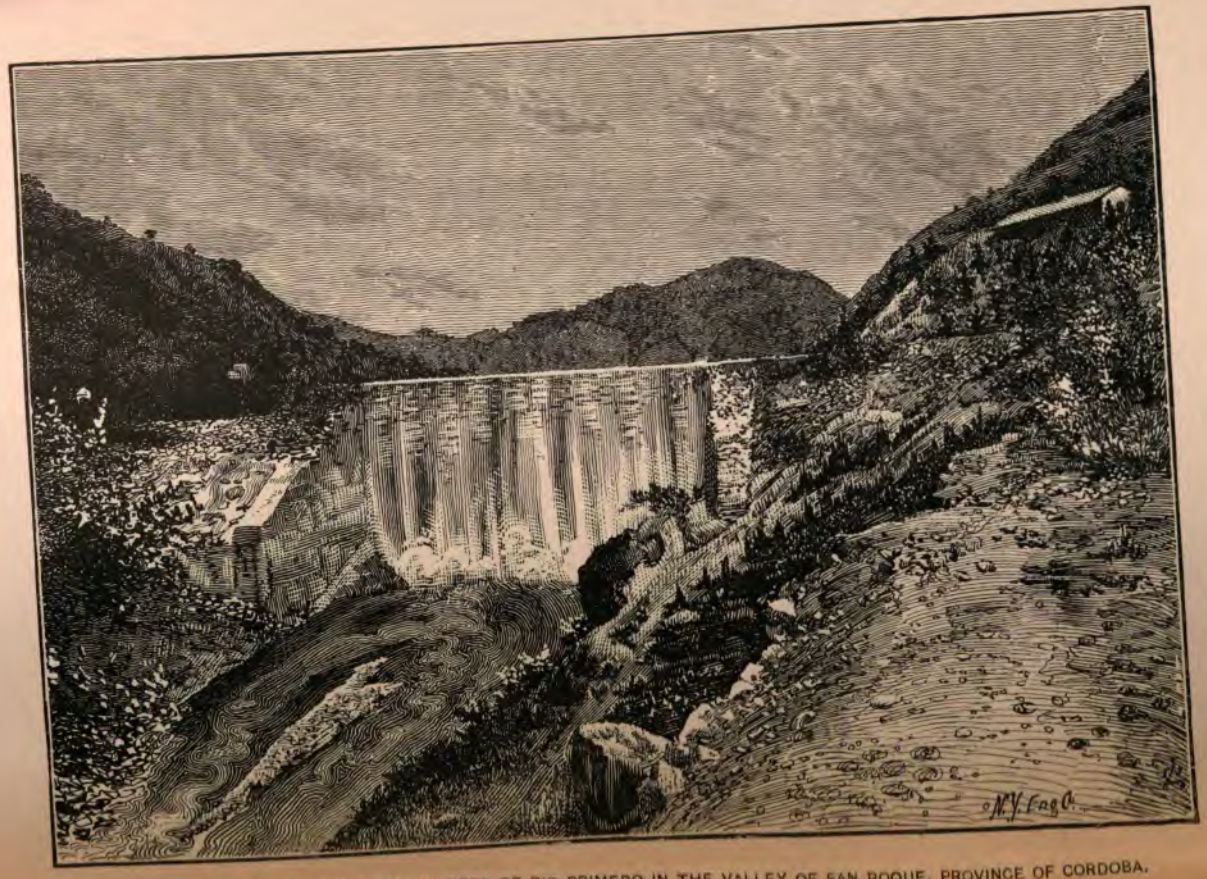
MENDOZA.—This province is bounded on the west by the line dividing Chili from the Argentine Republic, and contains about 155,745 square kilometers. A large portion of it is without population. The cultivated portions are mostly in the neighborhood of Mendoza, its only city, which is in latitude 32° 55′ and longitude 68° 49′, and stands at an altitude of 799 meters above the sea. It is situated in the foothills of the Andes. The meteorological office reports for the year 1886 the mean monthly temperature (centigrade thermometer) as follows:

	°		°
January	23.21	July	7 85
February	22.83	August	9.79
March	20.02	September	12.87
April	15.18	October	17.04
May	10.55	November	20.99
June	7.63	December	23.65

The mean temperature was 15.99°. The lowest temperature was 7.5° below zero on the 8th of August, and the highest 41.5° above on the 12th of December, a variation of 49°.

In regard to the rain-fall we have returns of the years 1877, 1878, 1879, and 1880, as follows:

Month.	1877.	1878.	1879.	1880.
January	19.0	0.0	0.3	0.5
February	5.5	11.0	3.3	9.0
March	0.4	7.0	97.0	28.2
April	18.5	2.0	5.0	0.0
May	0.0	8.0	0.0	0.0
June	0.0	0.0	14.0	7.5
July	0.2	1.0	0.0	9.0
August	0.0	9.0	10.0	0.0
September	0.1	15.0	2.0	17.0
October	0.0	3.0	65.5	21.0
November	57.5	10.0	8.0	0.4
December	0.0	0.0	7.5	41.0



I.—GRAND DIKE FOR HOLDING THE WATERS OF RIO PRIMERO IN THE VALLEY OF SAN ROQUE, PROVINCE OF CORDOBA.

The director of the meteorological office says:

From these figures will be understood the extreme aridity of the climate contiguous to the foot-hills of the Andes and that the entire agricultural richness of the Andine provinces depends directly upon the melting of the snows on the elevated peaks of the great Cordilleras. In the city, also, snow is accustomed to fall frequently during the winter, but to no great depth. And yet, owing to the extensive system of irrigation, the greatest part of the lands in the neighborhood of the rivers has been made very productive, being devoted principally to the cultivation of alfalfa, wheat, maize, and the vine.

SAN JUAN.—The province of San Juan lies to the north of that of Mendoza and its western boundary separates it also from Chili. Its mountainous features, however, are more pronounced than those of Mendoza, the Sierras there rising one behind the other in longitudinal chains which form the system of the Andes. The city of San Juan lies in latitude 31° 32′ and longitude 68° 35′, and it is 652 meters above the level of the sea. Twelve years of observations complete gives the mean monthly temperature of the city as follows:

	°		°
January	26.43	July	10.17
February	25.40	August	13.30
March	23.41	September	16.25
April	17.74	October	20.00
May	13.43	November	23.64
June	9.68	December	26.12

The mean temperature is 18.80°. The place is subject to very sudden changes of temperature, the varation in the summer months being sometimes as great as 25 degrees in a few hours.

I have returns complete of the rain-fall for the years 1881, 1882, 1883, and 1888, as follows:

Month.	1881.	1882.	1883.	1888.
January	35.0	3.0	39.0	40.5
February	55.0	12.0	12.0	16.0
March	0.0	0.0	1.0	8.0
April	0.0	0.0	0.0	0.0
May	0.0	6.0	1.0	0.0
June	0.0	4.0	0.0	0.0
July	1.5	0.0	1.0	0.0
August	15.5	0.0	0.0	0.2
September	0.0	0.0	0.0	0.0
October	0.0	7.0	6.0	8.0
November	26.0	0.0	0.0	2.0
December	14.0	0.0	23.0	16.0

It will be seen from these figures that the climate is excessively dry. The clearness of the atmosphere, however, is phenomenal, and although in summer the midday heat is very severely felt, the nights are refreshed by a cool breeze from the south. The "zonda," as the northeast wind is called, is the sirocco of South America, and prevails during the months of July, August, and September, generally beginning about 8 o'clock in the morning and continuing until sundown, during which time the heat is almost suffocating and the air is a cloud of dust. The "zonda," however, is always followed by a south wind, which at once causes a sudden fall of the temperature and re-establishes the atmospheric equilibrium.

In reference to the climate the director of the meteorological office says:

The quantity of water which falls is entirely inadequate to the requirements of life; and thus it is not astonishing that great tracts of country (travesias) are found almost entirely without vegetation unless the required moisture is supplied by irrigation. With even a limited irrigation, however, these deserts are transformed into fertile fields, which by the contrast seem, as it were, like islands of Paradise, where grow luxuriantly all the products of the temperate zone. The few rain-storms which occur are accompanied by violent winds and great electrical discharges, and hail frequently falls in the months of October and November, causing at times great destruction to the crops.

CATAMARCA.—The province of Catamarca is bounded on the west by Chili and on the north by Bolivia and the Province of Salta. Its superficial extent is placed at 242,309 square kilometers. Its great industry is mining, though considerable attention is also given to agriculture and the dairy. The city of Catamarca is in latitude 28° 28′ and longitude 65° 55′, and its altitude is 545 meters above the sea-level. It is situated in a small valley which on the south opens into a level arid plain. The climate is very similar to that of San Juan, very hot in summer and temperate in winter. The "zonda" here is very frequent and sometimes blows for forty-eight hours, in its progress frequently parching and blasting all vegetation. Indeed the climate is so dry that the drought sometimes continues for eight or nine months of the year. Only on such spots as are moistened by irrigation is any abundant vegetation to be found. The mean temperature for each month is given as follows:

	°		°
January	28.27	July	11.78
February	26.60	August	16.03
March	25.18	September	19.53
April	18.77	October	23.70
May	15.80	November	25.76
June	10.72	December	27.64

The temperature frequently rises above 40 degrees and scarcely ever known to fall to freezing-point.

I am not able to give the rain-fall, but it is much less than that of San Juan.

TUCUMAN.—The province of Tucuman is to the southeast of Catamarca, but in climate presents a very notable contrast to it, on account of its great humidity and consequently the tropical character of the vegetation. Indeed, owing to its innumerable farms and rich vegetation, it is called the "garden" of the Republic. Its superficial area is about 70,000 square kilometers, a large portion of which is relatively well cultivated the capital city of the same name is in latitude 26° 50′ longitude 65° 12′, and its altitude is 464 meters above the sea. I have the mean monthly temperature of Tucuman for sixteen years, and there is but little variation in the readings. I give that for 1885:

	°		°
January	25.0	July	11.3
February	23.1	August	15.1
March	21.0	September	19.3
April	17.4	October	20.1
May	13.6	November	24.5
June	11.9	December	24.5

The highest temperature recorded was December 25, 1862, when it went to 40 and on three occasions it went down to 0.9.

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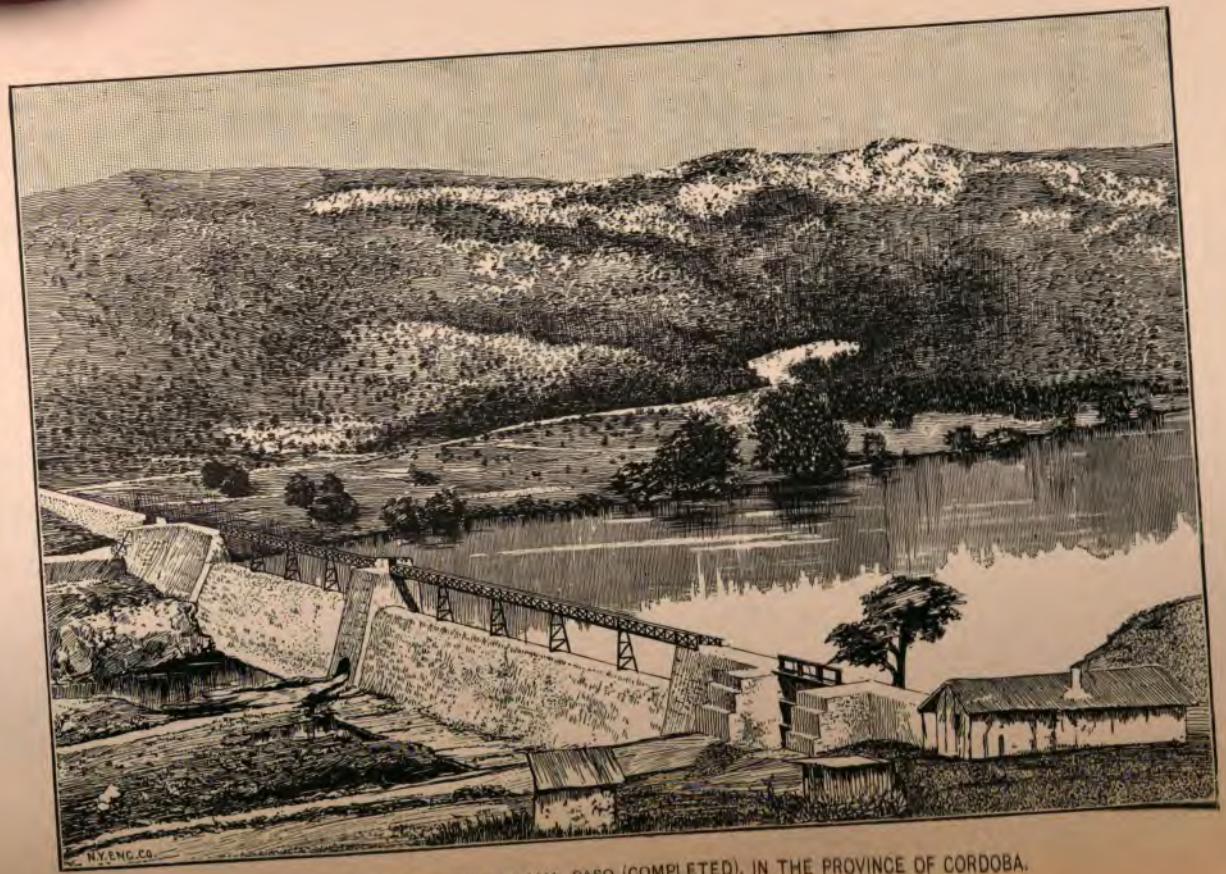
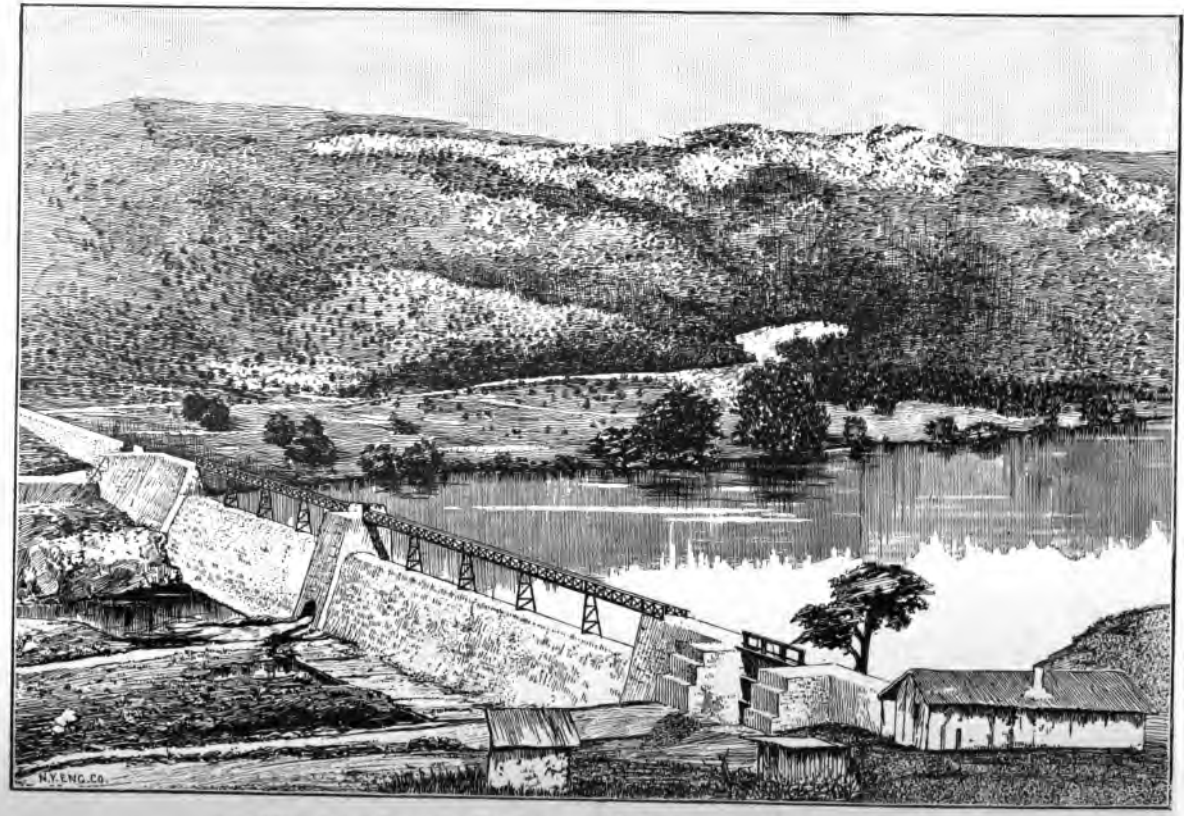


11.—DIKE OF DISTRIBUTION IN MAL PASO (COMPLETED), IN THE PROVINCE OF CORDOBA.



Report on Irrigation. II.—DIKE OF DISTRIBUTION IN MAL PASO (COMPLETED), IN THE PROVINCE OF CORDOBA.

The rain-fall for the years 1886, 1887 and 1888 was as follows:

Month.	1886.	1887.	1888.
January	307.6	328.0	85.9
February	241.2	95.1	48.7
March	201.1	119.6	211.0
April	26.5	30.3	44.4
May	8.0	5.5	12.0
June	21.1	4.9	29.2
July	0.0	31.8	4.5
August	2.3	2.0	1.5
September	5.6	14.2	65.5
October	40.5	100.4	83.6
November	93.1	97.8	168.3
December	115.2	106.0	221.4

The mean monthly rain-fall by seasons for the fifteen years was as follows: Spring, 205.3; summer, 488.2; autumn, 233.6; winter, 31.1.

CORDOBA.—The province of Cordoba is partly pampa and partly mountainous, and, exhibiting great diversity in the quality of the soil, is admirably adapted for agricultural pursuits and grazing, the only drawback being a tendency to droughts during the summer months. The city of Cordoba is situated on the banks of the Rio Primero, just on the edge of the great plain which extends to the Atlantic Ocean, the Sierras rising on the west to a height of 2,500 feet. I have the mean monthly temperature for the last fifteen years, and there is a remarkable uniformity in the figures. I give the following for the year 1887:

	°		°
January	23.4	July	10.5
February	22.4	August	16.0
March	21.0	September	15.5
April	16.3	October	17.7
May	12.7	November	19.7
June	12.7	December	21.6

The rain-fall likewise shows a remarkable uniformity. I have the returns for the last fifteen years, and the largest amount in any one year was 988.7 millimeters, in 1878, and the smallest amount was 528.7, in 1887. For the years 1887 and 1888 it was as follows:

Month.	1887.	1888.
January	91.4	15.3
February	47.8	66.5
March	30.4	130.1
April	68.4	0.0
May	10.5	67.0
June	0.0	2.3
July	7.0	0.0
August	0.0	0.0
September	3.0	9.5
October	49.0	31.6
November	136.3	119.5
December	84.9	161.9

The mean monthly rain-fall by seasons for the last eight years was as follows: Spring, 194.3; summer, 310.6; autumn, 144.3; winter, 16.1.

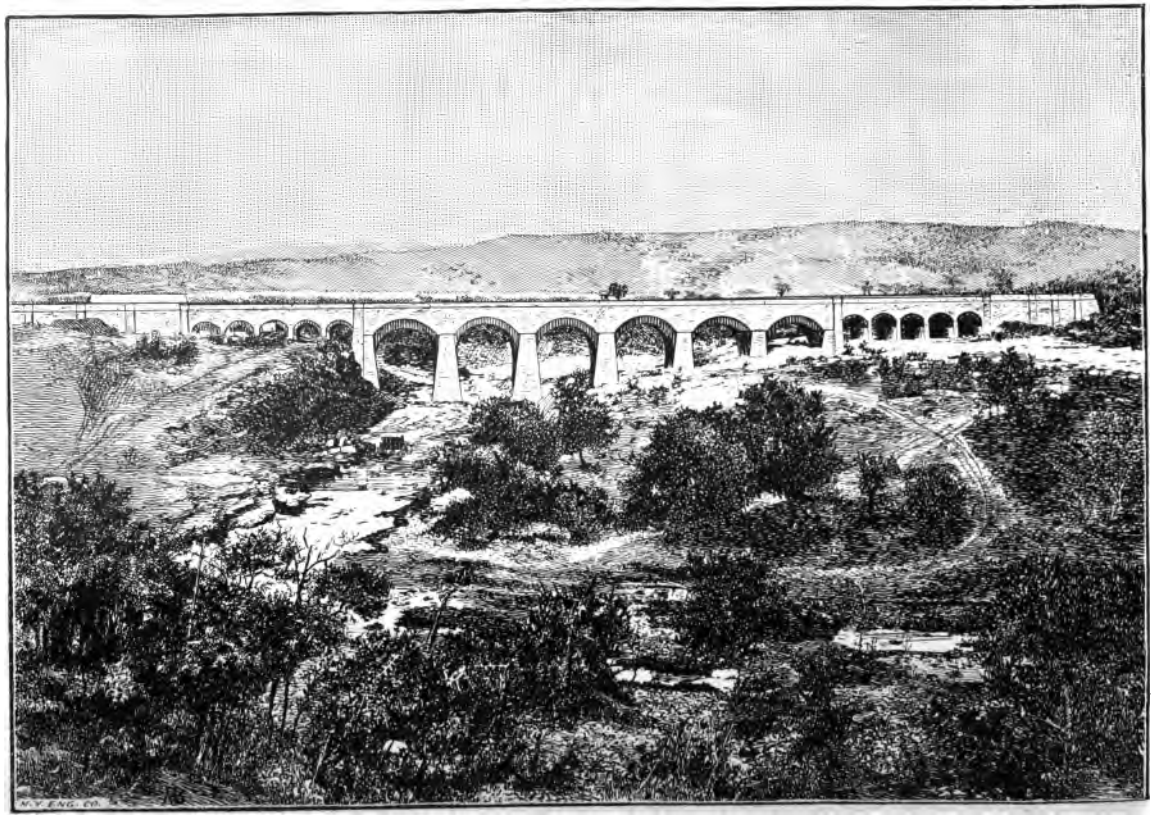
I might extend these meteorological returns, but they are quite sufficient to show the character of the climate in the irrigated regions, and the annual amounts of rain-fall. From an examination of them it will readily be understood that without some artificial means of watering the soil there would not be moisture sufficient for the production of crops with any certainty, unless, perhaps, in Tucuman and Cordoba.

SOURCES OF THE WATER SUPPLY.

The water supply in all these provinces for the purposes of irrigation is almost exclusively from rivers, streams, springs, and small water courses, coming down from the mountains. The great trouble, however, with those rivers which have their sources in the Cordilleras of the Andes is their unequal volume of water. With the melting of the snows, or during the rainy season, they are generally full to overflowing; but they soon run out and at the very times when their waters are most needed. Indeed, with the exception of the system of rivers which flow to the Rio de la Plate and which includes the Uruguay, the Parana, the Paraguay, the Pilcomayo, the Vermijo, and the Salado, there is not a single river in the entire Republic, until we come to the rivers south of the province of Buenos Ayres, which has any outlet. Those of the central system, most of which cross the province of Cordoba, after a dreary course to the eastward, are swallowed up in sands before they reach the Parana. Those which compose the system of the Cordilleras are all lost in quagmires and marshy lagunas before they reach the ocean. With their shallow beds running down very slight inclines, and their great evaporation from the high temperature of summer, many of them quite dry up during four or five months of the year, and these streams are all in those belts of country which have the greatest need of moisture.

CHARACTER OF THE IRRIGATION WORKS.

In regard to the character of the works used for the storage and distribution of the water, as a general thing, it may be said that they are of the most primitive kind. In most cases they consist merely in holding the waters by means of dams built at intervals along the courses of the streams and from the higher levels thus obtained, making canals or aqueducts through which the water is allowed to pass by a gradual descent as it is needed to the lands which are to be irrigated. From these canals the water is distributed by means of sluices and gateways along a system of drains, trenches, or conduits to the fields and meadows which compose the irrigation district. Where the surface is level or flat it is frequently necessary to form artificial slopes for the water to pass over. The whole of the ground is then laid in broad, undulating beds, the upper part of which is quite level from end to end, where the supply channel is cut. All the supply furrows are fed by a main channel at right angles to the beds and somewhat above them. When the flood-gates are opened the water flows into all the upper channels very regularly and evenly till it fills them to overflowing in their entire length. In the case of those streams which come down from the heights of the Andes and course through the valleys or cañons of the Sierras there is no difficulty in holding the water at a higher level than the lands to be irrigated, but where the sluggish rivers meander across an almost level plain, there is occasion sometimes for engineering and the taking of levels. In some instances a channel receiving the water at a higher point than that to which the river flows is dug at a less declivity than that of the bed of the stream and made to carry the water higher than the banks of the river, from which level it is allowed to descend slowly and irrigate the intervening district. In some parts of the Cuyo provinces the works which serve as reservoirs for retaining the waters are of solid masonry, and large sums of money have been spent in their construction. In other provinces the works are merely wooden barriers



III.– AQUEDUCT OF SALDAN OF THE NORTHERN CANAL OF THE IRRIGATION WORKS OF THE RIO PRIMERO, PROVINCE OF CORDOBA.

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or earth embankments, which sometimes in sudden freshets are swept away with great damage, thus leaving the people of the district, until they are repaired, without the means of irrigating their lands. I give below the various sources of the water supply.

JUJUY.—This province, which borders on Bolivia, is irrigated at various points by the waters of the river San Francisco, which, making a semi-circle through the southern valleys, finally empties into the Rio Vemejo. While it is the only considerable stream in the province, there are a large number of small mountain riverlets, from which channels also have been dug, and which greatly assist the necessities of agriculture.

SALTA.—On the other hand, this province is supplied with water for irrigating purposes from no less than three large rivers, the Juramento, the San Francisco, and the Vermijo, and by a large number of mountain streams, which are throughout their length utilized for agricultural purposes.

TUCUMAN.—Owing to the chains of mountains which longitudinally pass through the western portions of Tucuman, this province likewise is quite well supplied with water for irrigation purposes; on the south, the streams from the heights of the Aconquija range, from the river San Francisco, and on the east the river Sali, afterwards called the Dulce. These two rivers, together with an innumerable number of mountain riverlets, furnish an abundance of water for irrigation purposes, and nearly all the farms and sugar plantations are thus supplied through the means of ordinary conduits.

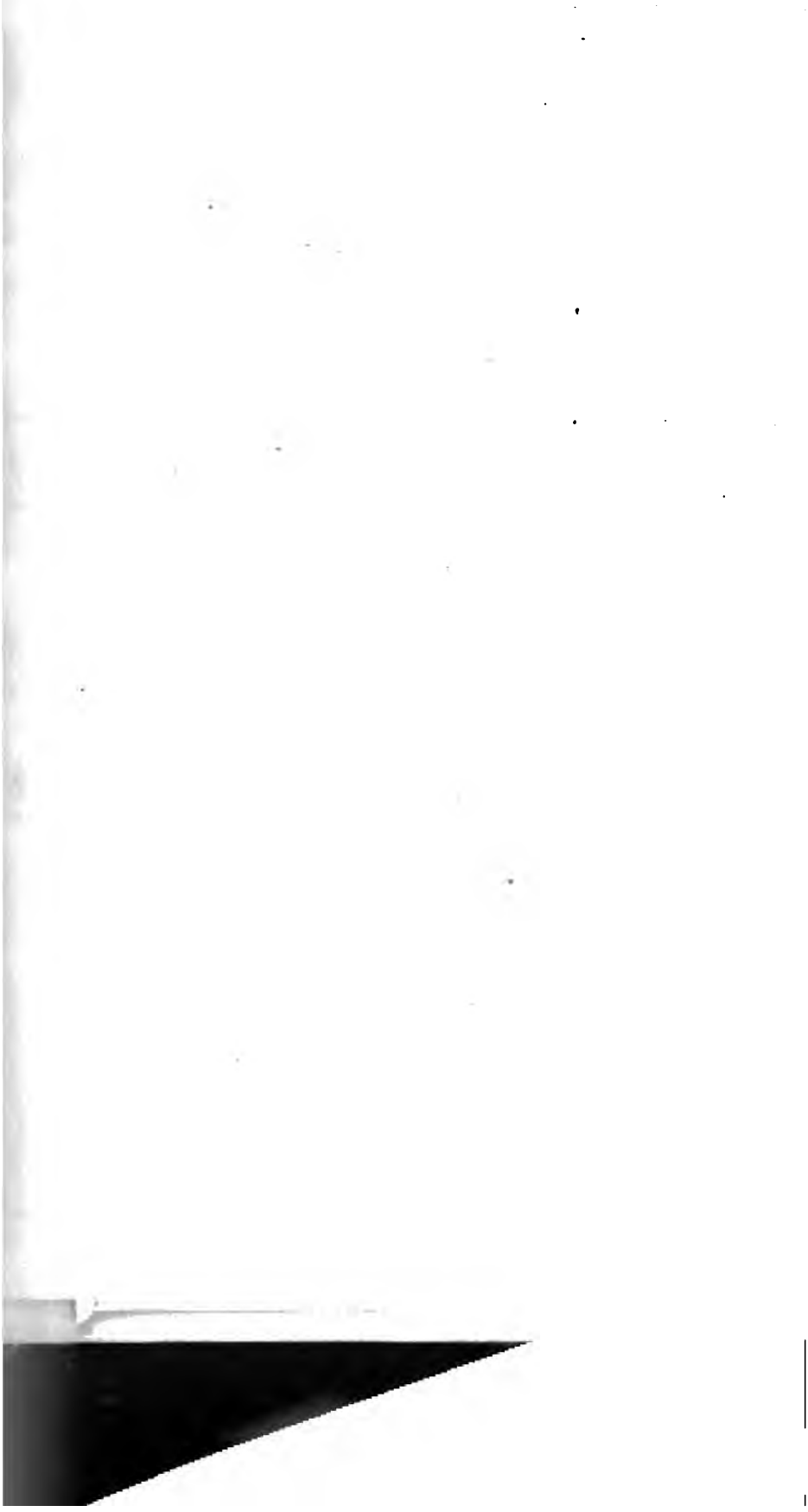
SANTIAGO DEL ESTERO.—In this province, the principal source of the waters for irrigating purposes is the river Juramento, afterwards called Salado, which flows along the northern and eastern borders. As far as Sepulturas the river is well banked and both sides are covered with fine farms and sugar plantations, the artificial watering which they receive from the stream producing a marvelous fertility in lands which otherwise would be perfectly barren. Beyond that point, however, it spreads out into marshes or esteros (whence the name of the province) over a country which is unfit for cultivation. Another considerable water course is the river Dulce, which, after leaving Tucuman, flows diagonally through the province, passing by the city of Santiago. In that vicinity it is well banked, and by means of a series of canals furnishes an abundance of water to the estancias and sugar farms on each side. Afterwards, turning to the southeast, it reaches the Salinas or great salt desert, where no vegetation can exist. Beyond this its several channels unite again and forms what is called the Saladillo. Along this stream are to be found spots or "oases in the desert" which have been redeemed by means of irrigating canals, thence coursing over a barren plain the river finally loses itself in an immense salt swamp called Los Porongos.

CATAMARCA.—This has no large water courses, though it is crossed by several small rivers, of which the principal are Santa Maria, the Paelen, and the Piedra Blanca, the two last named forming the Rio del Valle, on which the city of Catamarca is located. These streams and their affluents, and indeed every gorge and valley in the province down which courses a mountain torrent, are utilized ere they are swallowed up in the sands, for the purposes of irrigation. But even then the water supply is so inadequate, that there are throughout the province immense districts without water courses and without rain, which must continue to be little less than sterile deserts.

RIOJA.—Its only river of importance is the Vermijo, and this waters only a very small portion of its surface. This river, coming down from the eternal snows of Mount Boneti, traverses the fruitful valley of Jaque, is increased by the torrents which come from the Valle-Hermoso, and turning its course to the south to receive the surplus waters of the valley of Jacal, finally in latitude 32 degrees loses itself in the sand before reaching the lagunas of Guanacache. Throughout its course it affords excellent facilities by means of sluices for irrigation, but the volume of water is wholly insufficient to meet the requirements of the people, and during the summer months, for want of moisture, there are but few places which escape the wide-spread drought. Wherever there is a thread of water, however, coming down from the Sierras, it has been utilized for irrigation, and in the last few years the Government has been boring artesian wells in the hope of obtaining a better supply of water, but thus far with very little success.

SAN LUIZ.—This province is as poorly supplied with water as Rioja. The only river of any importance is the Rio Quinto, which comes down from the mountains in a series of cascades, and after a southeast course, is finally lost in the pampa, in latitude 34 degrees, in an immense salt-marsh called Juncal. There are several small streams whose waters are also, by means of dams and canals, utilized for the purposes of irrigation, but the great want in this province is more water; for although in good seasons there is rain-fall enough for the crops, yet this can not be depended on, and an adequate harvest is only certain in those parts where they have streams for irrigation.

SAN JUAN.—This province is in the midst of the rivers which compose the water system of the Cordilleras. The most northward of these is the Colorado, which is fed by several affluents from the far western Sierras. The second is the Vermejo Chico, which also is formed by several affluents in the snow-covered peaks of Copiapo, at whose foot are a series of magnificent farming districts, all watered by canals from these mountain streams. This river afterwards, turning to the south as I have said, makes its way towards the Laguna Guanacache, but is lost before it gets there. The third and most important of the group is the river San Juan, which has its source in the summits of the Cordilleras, in two affluents, and flowing to the east, down the valley of Pismento, cuts through the mountains and, after passing by the city of San Juan, turns to the south and empties into Lake Guanacache. Formerly, on the breaking up of the snows, the floods which came down this river caused most destructive inundations in the vicinity of the city, and sometimes devastated leagues upon leagues of the most cultivated parts of the valley. To guard against this, an immense dyke has been constructed which acts as a reservoir for holding the water during the summer months. From this reservoir have been constructed numberless distributing canals and conduits all along that beautiful valley; and the water is now so abundant that there is sufficient for steady streams along the gutters of the city. The San Juan all along its course, however, offers marvelous facilities for irrigation. At Murallon, its altitude is 800 meters, while at Lake Guanacache its altitude is only 600 meters, thus giving a fall of 200 meters in a distance of not over 40 miles in a straight line. The river, however, is wonderfully crooked, and affords water for an unlimited number of canals and conduits for fertilizing all the adjacent country. Besides this all the small streams and rivulets which find their way down from the mountains are utilized for watering the lands along which they course—indeed they are entirely absorbed for agricultural purposes.



MENDOZA.—The system of canals and conduits for irrigation purposes is probably more complete in Mendoza than in any other of the Cuyo provinces, and the absolute requirement of water for agricultural purposes gives its rivers and water-courses a peculiar importance. The most considerable of these is the Rio Mendoza, which is formed by two short branches in the eastern slopes of the Andes, the northern confluent descending from Mount Aconcagua, under the name of Rio Las Cuevas, while the southern, under the name of Rio los Horcones, receives its waters from the peaks of Tupungato. After the junction the river runs to the south through the valley between the Cordilleras, and the Sierra Uspillata, and reaching the level plain near Lujan, shortly afterwards doubles towards the north, in this way arriving at the Lake Guanacache, into which, like the Rio San Juan, it finally disappears. Throughout nearly its entire course, it furnishes the waters for an immense amount of irrigation, while the complicated net-work of channels in the immediate vicinity of the city, with their elaborate ramifications, is one of the great attractions of the place. Heretofore the waters, brought down and through the city in open trenches, was used indiscriminately, also, for drinking and culinary purposes, but two years ago, when the cholera visited this country, the epidemic was peculiarly malignant in that city, owing as the analysis proved, to the bad condition of the water in the canals. Since then, all water used in the city has been brought to it in closed pipes and is separate and distinct from that employed for purposes of irrigation; and the well-known healthfulness of Mendoza has once more been assured.

CORDOBA.—This province has probably greater facilities for extended works of irrigation than any other of the interior provinces, as it is crossed by not less than five considerable rivers, the Primero, the Segundo, the Tercero, the Cuarto, and the Quinto, all of which take their rise in different parts of the Sierras, which range on the western boundary of that province and flow to the east or southeast towards the river Parana, but which only the last named finally reaches, all the rest losing themselves in the sands of the pampa before they get there. These rivers are all utilized for irrigating the different portions of the province, as are also a number of still smaller rivers, which, rising in the Sierras of Cordoba, have their course towards the west until they finally also disappear in the sands.

With a view to increasing the agricultural facilities of the province and thus inducing immigration, five or six years ago, under the instigation of Dr. Juarez Celman, of that province, now president of the Argentine Republic, there was initiated a series of very extended works of artificial irrigation, the several rivers which run through its territory offering peculiar advantages for the purpose. Surveys and scientific inquiries to this end were made by corps of skillful engineers. The first of these works, under the name of the "Irrigation works of the heights of Cordoba" (Obras de riego de los altos de Cordoba) comprehended the distribution of the waters of the Rio Primero, which passes through the city of Cordoba. The work was commenced two years ago and it is just now contemplated and with most satisfactory results. The entire cost was $3,800,000. It is divided into four parts as follows:

(1) The dike of San Roque. This is a reservoir for holding the water of the river. It is located in a narrow cañon, with precipitous mountains on each side, at a short distance from the confluence of the rivers San Roque and Cosquin, which together form the Rio Primero. It is 51 meters in height and 37 meters from the water-line. The thickness of the wall is 51 meters at the base, laid in cement; 29

meters at the water-line and 5 meters at the top. Its length at the base, being from bank to bank, is 30 meters, and at the top 135 meters. It contains 50,000 cubic meters of masonry. It holds 260,000,000 cubic meters of water and converts the valley into a large and beautiful artificial lake. It contains two flood-gates, a pipe of discharge, and contrivances for removing the accumulations of sand. Upon leaving this immense reservoir, the water flows down the channel of the river until it reaches a spot called Mal Paso, a short distance from La Colera, where a second dike has been built.

(2) The dike of Mal Paso, which forms a reservoir for the distribution of the water. This dike is 10 meters in height and 230 meters in length, from bank to bank, and consists of 13,000 cubic meters of masonry. From this reservoir have been constructed two distributing canals, one of which carries the water to the table-lands on the north, and the other to those on the south side of the river.

(3) Main northern canal. This canal is 25 kilometers long and has eleven acqeducts, one of which, that of Saldan, for its extent, its solidity, and its elegance attracts general attention. The point of distribution is at a height of 37.25 meters above the threshold of the door of the National Observatory in Cordoba. The slope or declivity varies between 0.02 and 0.03 per 100 meters. It has twenty secondary canals. The amount of masonry employed in the construction is 44,000 cubic meters; the excavations of stone and earth reached to 615,000 cubic meters.

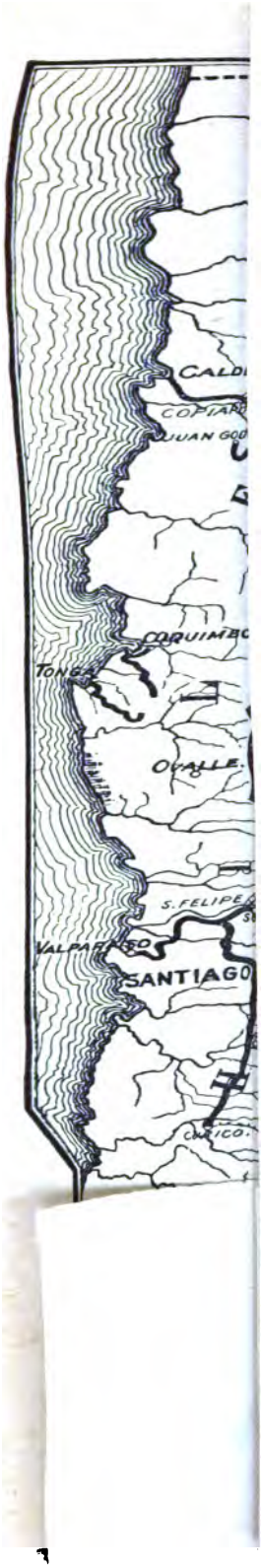
Main southern canal. This canal is 37½ kilometers in length, and has twenty aqueducts. The point of distribution is in a plain, even higher than that of the Northern Canal. The slope is the same. It has 89 kilometers of secondary canals. The amount of masonry employed in the construction is 45,000 cubic meters. The earth and stone excavations amounted to 842,000 cubic meters.

The area, which these colossal works will irrigate, amounts to 48,000 hectares at twelve floodings per year; and double that number at 6 per year.

Besides these, the surveys have been completed and approved for similar works on the Rio Segundo, which will hold 350,000,000 cubic meters of water and irrigate 60,000 hectares of land, at a cost of $4,500,000; also for works on the Rio Tercero, whose principal dyke will be 42 meters high and contain 286,000 cubic meters of water, at a cost of $3,850,000; also for works on the Rio Cuatio for which two dykes are to be constructed each 16 meters in height, which will hold 32,600,000 cubic meters of water and irrigate 17,500 hectares of land; also for the Rio de los Sances, which at a cost of $1,400,000 will irrigate 23,760 hectares of land.

The entire cost of the works completed and the works projected is estimated to be not less than $15,280,000 with a capacity to irrigate 1,209,250 hectares of land, which is equivalent to $73 per hectare. If all these works are ever completed the territory of Cordoba, which now in some parts, owing to the want of rain, is a desert, will take a new departure as an agricultural province.

I regret that I have not been able to be more explicit or go into greater detail in regard to the character of the works of irrigation in all the different provinces; but I have found it almost impossible to obtain any authentic information whatever. Upon the receipt of the circular of the Department, I at once applied to the interior department of the Argentine Government, in the hope that it could furnish me with printed reports, surveys or statistics in regard to the more important irrigation or storage systems employed in the interior provinces, but I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S. FELIPE
VALPARAISO
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was informed that it had nothing of the kind at its command. I then immediately addressed letters to the governors, stating the object I had in view and asking for such data on the subject as I supposed of course they would be able to send me; but although over a month has elapsed I have not yet received a word from any of them, and it is hardly worth while for me to delay my report any longer in the hope of obtaining them. Under these circumstances I have had to depend solely on such outside information as I have been able to procure, and except in the case of the works in the province of Cordoba, to speak only in a general way. In regard to the latter I have had access to a book descriptive of the province by Señor Santiago J. Albarracin, and which devotes a few pages to the subject of irrigation. In regard to the other provinces, however, the modes of irrigation employed are generally so primitive and so simple, being in most cases mere trenches with sloping slides, that I doubt if it would be of any service, even if I could give more detailed statements in regard to them.

DISTRIBUTION OF THE WATER.

In regard to the rules or laws which govern the distribution of the water, of course it all depends upon the tenure of ownership. In many of the provinces, if not indeed in all of them, there are numerous canals cut for irrigating purposes which are the property of the owners of the land, through or over which the canals are made. The province has had nothing to do with their construction and of course collect no rental or tax for the water used. Where the works have been constructed by the provincial governments a tax is paid by those who make use of the water, and this varies in the different provinces according to the expense or cost of the works. I regret that only in a few cases I am able to give the rates charged for the use of public water, not having been able to procure the laws under which the irrigating canals have been constructed.

In the province of Santiago des Estero, it is provided that all agricultural establishments and gardens which use the water of the public irrigating canals shall pay a tax of $1.50 per hour; and manufacturing establishments shall pay $2 each time they request the water, not to exceed four hours each time; for a single hour 50 cents each time. Subscribers for the use of the water for irrigation have the right to six times per month during the year; and in case they do not receive this amount in the course of the year, they are entitled to a proportionate rebate, but the law does not appear to state what amount of water shall be used.

In the province of Mendoza the annual tax is $30 per square (about 5 acres), the water to be used not oftener than one day in the week, the tax to be paid quarterly. For each house situated on the canals, where there is a service of water, a tax of 25 cents per month is charged. Those who make use of the water surreptitiously, or who use it out of their turns, must pay a fine of $20 for each offense.

In the province of Tucuman the water of the "Western Canal" is sold for the purpose of irrigation at the rate of $3 per mark per twenty-four hours; and for brick making at 30 cents per 1,000 bricks.

In Catamarca 6 cents per hour is charged for the use of the water from the Rio Tala, payable monthly.

In Cordoba the charge per square is $30 per year, payable quarterly, the water to be used one day in the week. Those who use the water out of their turn or without permission are liable to a fine of $20 each time

WATER RIGHTS BY PRESCRIPTION.

These water-rates, however, it will be borne in mind, are only collected in cases where the provinces are the proprietors of the works. In many cases, as I have said, the canals are the property of the land owners on each side of the stream. It is a part of the history of the conquest that when the Andine regions came into the possession of the Spaniards they occupied the country in the neighborhood of the rivers in some cases, driving the original inhabitants away from their settlements; and in others not only appropriating their settlements, but even reducing the Indians to the condition of slaves and requiring them to cultivate lands which were their own. These lands were held in vast estates, and with the organization of the governments it was found that all the arable places were in the possession of comparatively a few persons, who either found irrigating canals already constructed upon the lands or who compelled the enslaved Indians to dig them. Thus all these landed estates have had from the beginning a right to the use, if not the control, of the streams along which they are located. And, as with the increase of population, these estates have gradually been divided up into smaller properties and sold; a certain amount of the water for irrigating purposes have been sold with them. Thus the quantity of water which the different properties are entitled to is in most cases fixed by their title deeds.

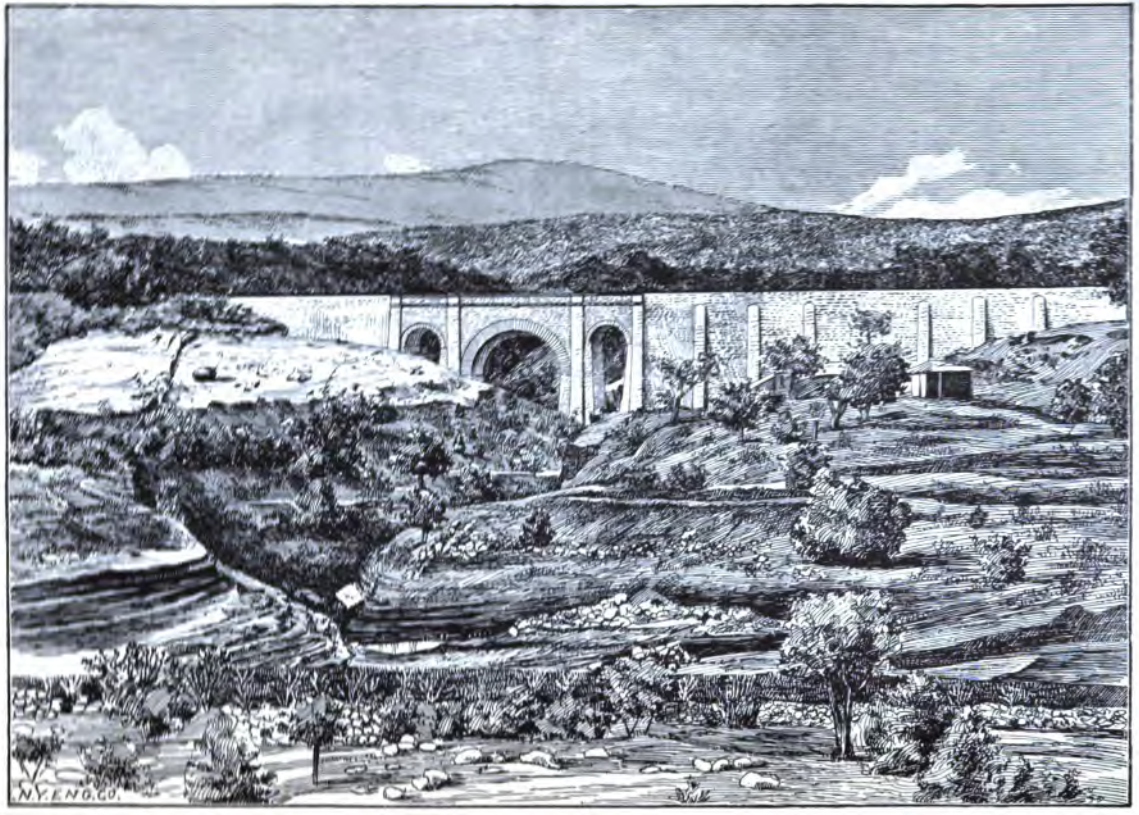
AREAS OF LAND UNDER IRRIGATION.

In regard to the areas of land under irrigation, compared with such as are cultivated without irrigation, together with the quantity and quality of the crops grown, it is not possible to speak with exactness. As no census of the country has been taken for the last twenty years it is usual to base all calculations on estimated figures, and that is all that can be done in this case. Fortunately I find in the message of the President of the Republic to the present Argentine Congress a table of statistics, "being the first ever attempted," giving the amount of land under cultivation in each province for the year 1888, compared with the total areas. I reproduce his figures below:

Provinces which depend on irrigation.

Provinces.	In cultivation.	Total area.
	Hectares.	*Hectares.*
Cordoba	234,395	17,476,700
San Luis	19,809	7,591,700
Mendoza	88,546	16,081,300
San Juan	79,630	9,750,500
Rioja	22,217	8,903,000
Catamarca	44,618	9,064,400
Santiago del Estero	120,400	10,235,500
Tucuman	35,943	2,419,900
Salta	38,525	12,826,600
Jujuy	18,994	4,528,600
Total	703,077	98,878,200

Thus, out of a total area of 98,878,200 hectares of land in these interior provinces, we find that only 703,077 hectares are under cultivation, being scarcely .07 per cent. of the entire area. It will readily be seen from this that it is only along the water courses that there is any irri-
-n, or indeed any vegetation at all.



IV.—AQUEDUCT No. 13, NORTHERN CANAL OF THE IRRIGATION WORKS OF THE PROVINCE OF CORDOBA.

The provinces which, owing to the frequency of the rains, do not require irrigation for the production of crops, are the following:

Provinces which have no irrigation.

Provinces.	In cultivation.	Total area.
	Hectares.	*Hectares.*
Buenos Ayres	868,658	31,123,700
Santa Fé	586,537	13,158,200
Entre Rios	136,151	7,545,700
Corrientes	46,631	8,114,800
Total	1,637,977	59,942,400

In these four riverine provinces out of a total area of 59,942,400 hectares of land, there are 1,637,077 hectares under cultivation, being about 2.5 per cent. of the entire area.

The President in his message calls attention to the difference in the percentage of land under crops in the riverine provinces and in the interior provinces, and says: "It shows the relation there is between easy means of communication and the cultivation of the land." There is no doubt that the outlet the formor have to the sea-board does give them some advantage, but the great advantage which they possess consists in their better climate and their more reliable supply of moisture from fertilizing rains. A large percentage of the lands in the interior provinces, owing to the limited supply of water they afford, beyond the immediate banks of their water-courses, must continue to be what it now is, an unproductive area of desert, unless the deficiency can some time be made up by the sinking of artesian wells, a problem which the Argentine National Government has for some time been trying to solve, thus far, however, without any great success. Should artesian water, however, be finally reached in sufficient quantities to meet the requirements of agriculture, all the interior provinces, most of whose areas are now but waste places, would receive a new stimulus and have a more prosperous future in store for them. They would then be able to produce crops not only of as good quality, but perhaps in as great quantities as the more favorable portions of the Republic. Until then, however, the provinces of the littoral must continue to be the chief centers of the Argentine agricultural industry.

PACIFIC OCEAN.

REPORT FROM H. W. SEVERANCE, U. S. CONSUL-GENERAL, HONOLULU, ON IRRIGATION IN THE HAWAIIAN ISLANDS.

This report has been delayed in order to include reference to a published report, now inclosed, on water-supply for irrigation by Messrs. Schuyler and Allard*. Thesee ngineers, being competent men, have examined the sources of supply on the island of Oahu, as well as giving valuable information concerning irrigation on the other larger islands of this group; and although this information is limited, the fact is fully established that irrigation is essential to success in the growth leading product, sugar-cane, as well as rice.

The only map bearing upon this subject is attached to the Messrs. Schuyler and Allardt. It has been difficult to obtai

* Report not received.

mation in an extended form but the points to which the circular alludes have as far as possible been answered in this report.

Where irrigation is continuous the product of sugar has increased to an average of 4 tons per acre, while the same lands without irrigation formerly yielded only the average of 2 tons per acre.

The area of good cane land is limited; the most reliable estimates do not exceed 90,000 acres. Of rice land 7,000 acres, and of land suited for bananas at present under cultivation 3,000 acres; total, 100,000 acres. Of the cane land about 45 per cent. is irrigated, the remainder, except for rice land, which is all under irrigation, is subject to the annual rain-fall, which is copious on the high lands on the windward or eastern side, while it is limited on the leeward or western side.

The quantity of sugar produced in the year 1888 was estimated at 120,000 tons. Two-thirds of this of a good light color, polarizing from 86 to 96°, and one-third of the yield polarizing from 76 to 84°, all of which was sold at good figures for refining purposes.

The estimate of rice was 20,000 tons, one-third of which was exported and the remainder consumed here. All of good quality.

Of bananas about 100,000 bunches; 75,000 exported, balance consumed here.

THE SOURCES OF WATER-SUPPLY.

From mountain streams, springs, artesian wells, and storage reservoirs.

THE CHARACTER OF WORKS, DISTRIBUTION, ETC.

These consist of dams and basins, by which water is imponded and then conveyed by wrought-iron and cast-iron pipes, flumes, and open water leads and ditches at various distances from 5 to 40 miles. This system of distribution is regulated largely by leases from land-owners and by custom and common consent with sanction of law.

AMOUNT OF WATER USED PER ACRE AND PER SEASON.

For twelve months' irrigation per acre on the Spreckelsville plantation on Maui 566,280 cubic feet were used, equal to 3 inches per acre, every week, or say 5.8 cubic feet for 1 pound of sugar produced. This may be a large quantity, as the usual estimate would be 1 cubic foot of water per second to properly irrigate 45 to 65 acres of cane or 30 acres of rice.

THE COST OF RENTAL TO USER.

On page 21 of report forwarded the highest cost of pumping is estimated at $3 per acre per month, or $45 per acre per crop. No reliable estimate can be found of cost of water-supply distributed by pipes, ditches, flumes, artesian wells, or springs. This would depend on the distance, the means of conveyance, the character of the country, and the flow.

TENURE OF OWNERSHIP OF WATER.

Both private and by lease from Government.

CHARACTER OF CLIMATE IN IRRIGATED REGION.

Variable, according to elevation; on the leeward or western side, in proximity to the ocean, dry; the eastern side generally moist and cool; good soil in the valleys, yielding fair crops.

ANNUAL RAIN-FALL.

Mean rain-fall on the island of Oahu from 1867 to 1883 was 62.6 inches (see page 24 of report inclosed), while the minimum rain-fall, along the coast exceeds 24 inches, and upon the mountain slopes from 40 to 90 inches, according to elevation; in the Hilo district on Hawaii, 120 inches.

ANTIQUITY OF IRRIGATION SYSTEM.

A system of irrigation has always existed among the Hawaiians throughout the Kingdom, conveying the water from the mountain slopes and springs through the valleys over hill-sides for the production of their chief article of food, the *Arum esculentum* or kalo, from which poi is made. Many of the ancient water leads are still maintained at private expense by the owners of leases of the land running from the mountain to the sea.

ASIA.

REPORT FROM JOHN TYLER CAMPBELL, U. S. CONSUL, FOOCHOW, ON IRRIGATION IN CHINA.

As the rain-fall is equally distributed throughout the year in this province (Fohkien) there is no land dependent alone on irrigation; but in the culture and growth of rice, which is generally understood to be the principal crop grown here, irrigation is at times indispensable, and is a subject which deeply concerns the farmer in this country. The rice crop can not be made without a great deal of water, and in the seasons of drought its absence is sorely felt.

THE CULTIVATION OF RICE.

In the first place a small piece of ground is highly fertilized, plowed, or dug up and put in good order very much as cabbage beds are prepared, then the rice seeds are sown, after which the water is turned on and the bed kept submerged with about a half of a foot of water until the plants are sufficiently large to be transplanted to the fields. And here again irrigation is required. The ground is plowed and put in order for the plants, but before planting the fields are covered with water about one-half of a foot deep and the soil is worked into mud; the plants are then set into the mud and water in rows. Water is kept standing on the land until the plants are well along. Irrigation is therefore essential to rice growing.

HOW LAND IS IRRIGATED.

This country is well situated for the construction of reservoirs on a large scale. Dams could be easily built across the gulches and deep cañons in the mountains, and reservoirs could be made wherein immense quantities of water could be stored and when needed for irrigation could be turned on the fields in the valleys below by the force of gravity, but this idea has never been acted upon by the Chinese, if it ever entered their minds. Small ponds are made adjacent to the fields, and the water is pumped from these and the natural water supplies into the rice fields by man power alone.

THE MODE OF IRRIGATION.

The water used for irrigation is drawn up from the ponds and watercourses by an endless chain, or rather an endless rope pump, which is worked by one man or sometimes two men by treading upon a wheel, made with a number of radiating arms, which causes the wheel to turn upon its axis. A horizontal pole about 5 feet above the shaft is made fast, and the men support themselves by leaning upon this pole while treading the wheel. One end of the box through which the chain draws the buckets is placed in the water at an angle of about 45 degrees with the pond, river, or canal from whence the water is drawn into the field. The box is open at both ends and is made strong and light. The whole apparatus is easily carried by one man on his shoulders. The faster the man treads the wheel the more water is pumped, and the machine is kept going night and day when water is needed for irrigation.

The pump is run very much on the principle of the tread-mill so far as the motor-power goes, and the water is carried up with the buckets something like wheat is raised in an elevator. In this province neither horse nor steam power has ever been thought of, and the manner of pumping water it is believed has not changed for three hundred years. Water is conducted into the fields, which are usually marked off into small compartments, according to the number of proprietors, by earth embankments, the water filling one after another until all are covered. Horses are never used in this province by the farmers, and in fact are rarely seen here. Everything is carried by human beings on their backs. The vegetable garden, flowers, and small plants are watered by water carried on the backs of the laboring people—men, women, and children.

None of the modern appliances for conducting water over the land have as yet found their way into China. No greater or stronger power than human hands is ever called into requisition, nor is there any likelihood of any innovation to the long-established custom being permitted in this land where farms are so small and labor so cheap. No farmer will expend money in experiments for irrigation when he can hire a laborer at from $10 to $12 per year to keep the time-honored pump in motion. The working classes themselves would strongly oppose the introduction of labor-saving inventions that would take work from them, and tend to cut off their employment. The farms are small, less than 1 acre in many cases, but they have been tilled for perhaps thousands of years, and by the skillful use of fertilizers and by care and attention to each plant crops are raised that would astonish the owners of rich soil.

THE WATERS OF THE RIVER MIN.

The river Min runs diagonally through this province, and a few miles above this city it divides into several branches, which, after pursuing separate courses for 15 miles, unite a little above the pagoda anchorage, and empty into the Pacific Ocean 2 miles below. Along the river are numerous small valleys which can be easily irrigated from the river, but the mode of irrigation is rude and simple. The pump is used for the larger fields and small plants, and garden vegetables are watered by water carried on the backs of the laboring people. The everlasting pole on the shoulder of the bearer, with buckets suspended from each end, is rarely out of view. The water is carried in this way, in many places a long distance, but no complaint is heard in any quarter. When the rains cease water must be supplied to keep alive the growing vege-

tation so essential to the existence of the people. During a dry season men, women, and children are engaged in carrying water which is carefully sprinkled over the vegetation, and the greatest patience and care are shown in keeping moisture about the plants. In this part of China the rain-fall is fairly distributed throughout the season, but if the rain does not come at the needed time the water buckets are called into requisition to supply the necessary water for the crops.

LAND UNDER IRRIGATION.

There are no means of ascertaining the area of land grown in rice. This seems to be the only product of the soil that necessitates irrigation. There are no statistics available showing the quantity of land under cultivation. As far as observation goes the whole face of the country, excluding the precipitous mountains and running streams, is used either for farming purposes, for residences, or for cemeteries. The water-supply is abundant for all purposes in ordinary times. There are numerous rivers, streams, and springs in all parts of the province. There are no laws governing the use of water. Custom rules in this as in almost all the affairs of life in China.

REPORT FROM THOMAS F. PETTUS, U. S. CONSUL, NINGPO, CHINA, ON IRRIGATION.

(1) It is impossible to ascertain the areas of lands under irrigation or cultivation, owing to the difficulty in getting at the records kept in the tax office and the absence of published returns of land taxes. The district is well cultivated, and every strip of land available is under cultivation.

(2) The supply of water for bottom land is from canals. The supply canals are run from the river to the hills, dug from 50 to 80 feet wide. At the foot of hills all running water from springs is emptied into the canals, so as to form a never-failing supply of fresh water. The canals are not allowed to connect with the river, as the water in the latter is salt or brackish. At the foot (or end) of the canal an embankment of stone is made to a height above the sides of the river, this is covered with moistened, slippery clay, so that boats entering or leaving the canal are hauled over. A hawser of twisted split bamboo is fastened either to the stern of the boat or a strong beam crossing it at the bows. The hauling is usually done by capstans, sometimes by oxen.

These canals have no locks. The supply canals are from 2 to 4 miles apart; minor canals are dug at right angles, and supplied with water from the main arteries, about 200 to 400 feet apart, from 10 to 30 feet wide. Thus every farm and garden is supplied with free water.

(3) The farmers, when compelled to irrigate their land, use a wooden chain-pump, which is as long as required, placed so as to draw water from the canals, worked by cog-wheels, the ox performing the labor; so a stream of water some 10 inches wide constantly flows. A field of 2 or 3 acres of rice is soon overflowed.

For gardens and small plots of ground a hand-pump of the same kind is used, generally worked by two men.

The hill lands are terraced and are irrigated by springs, water being conveyed by small ditches or by pipes made of bamboo.

(4) There are no laws or rules governing the water system. The canals are free, and there are no expenses to the user beyond those of drawing the water from the canals.

and September, hot and dry; November and December, dry and pleasant; January, February, and March, damp and disagreeable.

The system of irrigation according to Chinese is over a thousand years old.

The soil is alluvial. Rain-fall for 1888 was 68.31 inches.

REPORT FROM CHARLES SEYMOUR, U. S. CONSUL, CANTON, CHINA, ON IRRIGATION.

(1) Irrigation of land is so general in southern China that a comparison between irrigated and non-irrigated lands is impossible. Rice is the chief crop on which cultivators rely for support, but near Canton and other large towns and cities a great diversity of productions may be found, as vegetables of all kinds are cultivated, and the lands being so subdivided as to be devoted to small parcels, and under the management of small owners, to many kinds of crops, with a view to early supplies for immediate city consumption.

The yield of good land,* which has been properly fertilized and irrigated, supports a family of five persons, who will each consume 2 pounds of rice, and other things in moderate variety and supply. Two crops of rice and one of vegetables are produced annually when the land is well tilled. A ton and three-quarters of rice per acre each year is a fine crop. In tilling the small pieces of land about Canton, with a generous use of fertilizers, the utmost vigilance is given to irrigation.

(2 and 3) The sources of water-supply are the small tributaries of the large branches of great streams, and in many places where they are inaccessible pools of water are held in reserve by hardening the bottoms and sides of pits and hollows and depressed or sunken lands. Between rows of growing vegetables, trenches filled with water, obtained from the creeks, brooks, or pools, are kept, and once or twice a day the water is scooped from these trenches upon the raised grounds, in which the roots have great depth of loose and moist soil to promote growth. When these trenches of water are not available, owing to scarcity of water or to porous land, the men and women carry, suspended from a yoke across their shoulders, two large buckets with long spouts, and sprinkle the rows of vegetables copiously. Sometimes the water for this purpose is carried in buckets a considerable distance. For the irrigation of rice lands, which have to be submerged, the lands are divided into small patches at different levels, so that the appearance is that of a beautiful system of terraces, near a bountiful supply of water, which is raised to the upper level by chain-pump and tread mill process with coolie power. From the upper to lower levels the water descends so gradually as to avoid washing away the substance or fertility of upper to lower lands.

(4) The system of water distribution is generally conducted and used on the mutual or co-operative plan, which prevails in China in so many branches of industry and business as to lead one to believe co-operation is reduced to a perfect system on the basis of equity.

(5) The character of the climate in this province is mild and warm. The lowest temperature at Canton in winter is about 37 or 38° Fah. The rainy season of March and April, with copious showers and rains of considerable frequency during May and June, and occasional show-

*The consul makes no mention of the area required.

ers up to the end of August, supplying crops with abundant water when most needed for the first and second rice crops. The actual measurement of rain-fall is not known. During the rainy season the water-fall is torrential at times.

The antiquity of the irrigation system in China is established. This portion of China is favored with streams, and water-ways, sloughs, and natural deposits of water for the temporary season of drought; so that being abundance of fertilizing properties available for agricultural and horticultural operations, the excellent supply of water required for irrigation of land favors the production of the largest crops of which any land is capable of yielding.

REPORT FROM A. C. JONES, U. S. CONSUL CHIN KIANG, CHINA, ON IRRIGATION.

SIR: In compliance with the circular letter of instructions of the Department of State, on the subject of irrigation, dated May 2, 1889, and received on the 7th instant, I have the honor to inform you that, so far as I can learn, there never has been any national or other governmental system of water distribution in China. There are no reservoirs worthy of the name in any part of the country. This province of Kiangsie, as its name signifies, is the province of rivers and mulberry trees, and is perhaps the best-watered section in the empire. The almost annual inundations, caused by the overflow of the Yellow River and the Yangtsze Kiang, fertilizes the submerged lowlands of the province and renders unnecessary any artificial means for the cultivation of crops except that of rice, which requires in the early stages of planting and growth a great deal of water.

The methods of providing water for the rice and other crops in general all over the country are very simple, and are governed by no laws or regulations beyond the local customs of the people.

The farms, so-called, are rarely over 2 acres in extent, and are separated by ditches or raised pathways. There are no fences and no ranging stock.

To provide a water-supply for the fields the farmers usually club together and make large pools to receive the rain for common use. It is then when required supplied to the fields by pails. When a natural streamlet exists, it is utilized by conducting it through ditches or bambo pipes to the fields.

Sometimes the water is supplied from the streamlets by the most primitive arrangement of a water-wheel worked by treading with the feet.

These are the methods in vogue since the earliest days in this district, and no improvements on them have ever been attempted. In other districts I have seen the water-wheel worked by buffaloes.

The rain-fall is very uncertain. Usually in May and part of June there are heavy rains; but last year a long-continual drought almost destroyed the whole rice crop of the district.

In reading of the astuteness of the Chinese and of their reputation generally as to shrewdness and sagacity, one naturally would expect other things of them; but my observation of the working class and the farmers leads me to the conclusion that while they are hard-working and patient, they are a shiftless and hand-to-mouth people.

REPORT FROM J. D. KENNEDY, U. S. CONSUL-GENERAL, SHANGHAI, ON IRRIGATION IN CHINA.

Following the Department's inquiries in their order I have to report as follows:

(2) Rice fields are usually flooded from rivers, streams, and canals.

(3) There is no system of storage of water for irrigation.

(4) All irrigation throughout this section of China (if flooding rice fields may be called irrigation) is carried on by individuals. No further information under this heading obtainable.

(5) Warm, moist, and fertile.

(6) The present means of pumping water from streams into fields has been practiced in China from time immemorial.

In general: From Mr. G. James Morrison, an English civil engineer, who has had much experience in China, I learn that from observation made during extensive journeys in the interior of this country he has seen no other means of irrigation than the system of pumping from streams directly into the fields, save the more laborious method he saw in the northern sections of China of lifting water in buckets and throwing it over the bank by hand.

On the island of Formosa he saw a more extensive system of irrigation, the water being conducted down the hills for some distance.

From Mr. John Fryer, a distinguished sinologue, to whom I applied for assistance in making this report, and who obtained his information from Chinese sources, I learn that in northern Shan-Si an arid tract of land has been reclaimed by irrigation. The information is so meager that I merely mention it. In many sections of China there is at the present day extensive tracts of arid land and no attempts are made to reclaim them.

REPORT FROM JACOB I. CHILD, UNITED STATES CONSUL-GENERAL, BANGKOK, ON IRRIGATION IN SIAM.

About one-half of the country is under cultivation, and of this portion fully four-fifths is under irrigation.

Rice is the staple, consisting of two kinds, Va Suan, or garden rice, which is tranplanted, and the second grade, Va Muang, or field rice.

It is estimated that about 10,143,800 piculs are annually grown in Siam.

Water is supplied to the fields by means of canals, which branch out from the rivers in all directions.

The water is conducted into the fields by small canals and ditches (the fields are divided off into ris, containing about one-third of an acre), around the four sides of each ri, in turn, until the whole number of ris is full.

There are no published works upon irrigation. This system is governed by laws and customs. There is no duty upon the water, but if the land is government property there is an annual rental in the form of a tax of 28 cents per ri, which includes the use of the water. The large canals are built at the expense of the general government, but the small canals leading to the fields must be dug by the individual.

The climate is tropical, with a wet and dry season. The average annual rain-fall is 67.04 inches.

The system of irrigation has been in use from time immemorial and is maintained partly by public and partly by private expense.

REPORT OF ERHARD BISSINGER, U. S. CONSUL, BEIRUT, ON IRRIGATION, ETC., IN SYRIA.

(1) AREAS OF LAND UNDER IRRIGATION, ETC.—As there are no statistics kept in Syria it is not possible to state with any degree of positiveness the exact areas of land under irrigation, and the different authorities competent to speak on so important a subject differ somewhat in their various estimates. A high government official in Damascus, who has devoted much study and attention to the matter, gives the approximate area of cultivated land in the vilayet or province of Syria as 30,000 feddans—336,000,000 square feet. (A "feddan" in Syria is understood to comprise that extent of land which can be plowed and prepared for seed by a pair of oxen in one day.)

An equally reliable and competent authority in Beirut, from his own observations and knowledge of the country, estimates that only about 5 per cent. of the cultivated lands are irrigated in the province known as Mount Lebanon, and probably not over 2 per cent. in all Syria, while the proportion of irrigable, as compared with non-irrigable, areas is calculated by the former authority as equal to about three parts out of twenty-four, or 12½ per cent.

Quantity and quality of crops grown.—The total quantity of crops grown is not ascertainable, not even approximately, and any attempt to arrive at exact figures would be useless and a mere waste of time.

The quality of the crops varies according to climate, soil, and locality; they comprise nearly all the cereals grown in the United States, besides "durah" or maize (both yellow and white), sesame, hemp, cotton, etc., also bananas, pomegranates, figs, dates, oranges, lemons, mulberries, olive, and other fruits, and all kinds of vegetables and other garden products.

Orchards well watered, as those for instance at Sidon, Tripoli, and other places in Syria, are reputed to be very remunerative in a pecuniary point of view, yielding, it is said, as high as 10 per cent on the capital invested, clear of all expenses.

(2) *Sources of water supply.*—The sources of water supply are lakes, rivers, streams, and other water-courses, springs, ponds, wells, and cisterns or tanks. The waters of lakes for irrigation purposes are only utilized in a few instances, such as Homs, Tiberias, etc., as will be seen later on, and reservoirs, on a large scale, do not exist at all in Syria.

(3) *Character of works used for storage and distribution of water.*—Published reports of irrigation and storage works do not exist; a wood cut of a huge Persian water-wheel in use at Hamah, with an accompanying description in print published from notes furnished by a competent authority here, is all I have seen.

Generally speaking the character of the irrigation works is of the most primitive kind. From rivers the conveyance of water is usually by means of canals or rough ditches badly leveled and aligned, often without masonry except at the intake, the retaining weirs for obtaining necessary head being remade every season of bowlder, stones, and brush-wood, rarely over 3 feet high.

Irrigation from springs is generally much the same as from the rivers, though necessarily on a smaller scale.

From wells the system universally employed is that of the "Na 'hura."

The "Na'hura" is of the simplest construction, cheap, quickly made and repaired, and easily worked, while it raises a comparatively large quantity of water. Its construction consists of a clumsy cog-wheel,

mule, or horse attached to the sweep; this turns a similar one perpendicularly placed at the end of a heavy beam, which has a large wide drum built into it, directly over the mouth of the well.

Over this drum revolve two rough hawsers, or thick ropes, often made of "myrtle" twigs and branches twisted together, and upon them are fastened small earthen jars or wooden buckets. One side descends while the other rises, carrying the small buckets with them; those descending are empty, while the ascending ones are full, and as they pass over the top they discharge into a trough which conveys the water to the cistern. The length of the hawsers and number of buckets depend upon the profundity of the well, for the buckets are fastened to the hawsers about 2 feet apart; the wells are of different depths, but generally average from 10 to 15 feet. It is claimed that with good animal power a bucket containing about 2 gallons of water can be raised every second (see table in "Acca-Haifa" report).

The "Shaduf," so conspicuous on the Nile, is not used in Syria, but on the shores of Lake Tiberias an apparatus much like it has been seen at work, and the well-sweep and bucket is also met with in many places.

Another method (very common in the land of Philistia) may be observed on the plains of central Syria. It is a large buffalo skin so attached to cords that when let down into the well it opens and is instantly filled, and being drawn up, closes up so as to retain the water. The rope by which it is hoisted to the crop works over a wheel and is drawn by donkeys, mules, oxen, or camels that walk directly from the well to the length of the rope and then return, only to repeat the process until a sufficient quantity of water is raised; this is also a very successful mode of drawing water.

The wheel and bucket, of different sorts and sizes, are much used where the water is near the surface, and also along rapid rivers. For shallow wells merely a wheel is used, whose diameter equals the desired elevation of the water. The rim of this wheel is large, hollow, and divided into compartments answering the place of buckets. A hole at the top of each bucket allows it to fill, as that part of the rim, in revolving, dips under the water. This, of course, will be discharged into the trough when the bucket begins to descend, and thus a constant succession of streams falls into the cisterns. The wheel itself may be turned by donkeys, mules, oxen, or camels.

Small water-wheels are sometimes turned by feet, but the process is tedious, toilsome, and not productive of much result.

At Homs, in the Tripoli district, there is a lake or artificial basin of about 4,000 acres in extent, formed by draining the Orontes River. It is very shallow in summer, probably not over 10 or 15 feet at the deepest part, but will reach a depth estimated at from 30 to 40 feet in the winter. The lake was made for the double purpose of regulating the summer flow of the Orontes and for obtaining sufficient head of water to irrigate the extensive gardens of Homs. This lake is the only artificial system of irrigation on a large scale in the country, but it is not kept in very good repair.

The "Pools of Solomon," at Tyre, may also be mentioned; they are natural artesian wells of great volume, irrigating some 1,500 acres of garden land from artificially raised conduits.

(4) *The system of water distribution, etc.*—In regard to this, Ottoman law literally says:

> In contestations relative to water-courses for drinking or irrigating purposes, the customs and usages existing *ab. antiquo* only are to be taken into consideration.

These usages and established rules vary somewhat in different localities; but it is the almost universal custom that the water belongs to the community and to the lands irrigated by it; the allotted quantities of water can not be altered or alienated without the permission of all the proprietors unanimously; nor can the lands be sold without the water, nor the water without the lands.

The amount of water used per acre—is estimated by a reliable authority as varying from 25 tons in the plain for garden products to 4 tons per acre in the high lands for mulberry trees.

The actual or precise quantity of water used per acre or season, can not, however, be accurately stated; it varies greatly according to the soil and its products. Mulberry trees, for instance, need only to be well watered three or four times during the dry season; but the water should penetrate the ground at least 3 feet. This would require the the land to be inundated to a depth of at least 8 to 10 inches. Vegetables, cereals, etc., should be watered more frequently, at least once or twice a week.

Where there is scarcity of water, judicious manuring would do much towards assuring good crops; but this practice, outside of the vicinity of Beirut and other large cities, is either wholly unknown in Syria or only resorted to in very isolated cases.

Tenure of ownership of water, etc.—The Turkish regulations and laws are very comprehensive and precise on this subject, and for a fuller understanding of the same, a translation of the most pertinent paragraphs is appended herewith:

OTTOMAN REGULATIONS CONCERNING PROPRIETARY RIGHTS OF WATER, ETC.

Water, herbs, and fire are things *ex commercium*; all men enjoy them in common.

Water running under ground is the property of no one in particular.

Wells not sunk by any one in particular and which are used by the public in common, are *ex commercium*.

Seas and great lakes are things *ex commercium*.

Streams of the public domains, that is to say, those which do not specially belong to any one, are those whose bed is not the property of a number of persons; such streams are *extra commercium*, as for example, the Nile, the Euphrates, the Danube, etc.

"Private" streams (Arabic, *enharmunlouké*), *i. e.*, those whose beds traverse the lands the property of private persons, are of two kinds.

First. Those whose waters are subdivided among co-proprietors, but which do not empty or exhaust themselves completely into the lands of the latter and which run afterwards into public rivers; such water courses are also designated "public," because part of them is public domain. The right of pre-emption (chufaa) is not applicable to these water courses.

Second. "Private" water courses (nehrihass) which run within the limits of the property of a given number of persons and whose water is exhausted and disappears upon such property without re-appearing to form another confluent. Pre-emption rights are only applicable to such water-courses.

Alluvium deposited by a stream on the land of a private individual becomes that person's property; no one else can lay claim to proprietary rights thereto.

Herbs of natural (wild) growth upon lands the property of no one in particular are *ex commercium;* the same with herbs that grow upon private property unknown to the owner; but if the latter waters his land or incloses it with a view to prepare it for cultivation, then the herbs growing thereon become his property; no one else can appropriate them, and he who gathers them is held responsible therefor.

By herbs are meant such plants as are not artificially watered; mushrooms, for instance, are included therein, but trees are not. Trees of natural growth (*i. e.*, wild growth) upon mountains which have no owners (djibali moubalra) are *ex commercium*.

Trees of natural (wild) growth upon the property of any one belong to the owner of such property; nobody can cut them down without his authorization. He who grafts a tree becomes the proprietor of the shoots and fruits thereof.

If anybody occupies a thing *ex commercium* he becomes the exclusive proprietor thereof.

Examples: The water which a person draws from a stream with a receptacle becomes his undisputed property, and if a third person consumes it without the owner's permission he is held liable therefor.

The occupation of a thing must show intent; consequently he who has placed a receptacle with the intention of collecting rain-water becomes the owner of such water.

The same with water accumulated in a basin or cistern; but the rain-water found in a receptacle not expressly placed for such a purpose is not the property of the owner of the receptacle, and other persons may appropriate such water.

It is necessary in the occupation of water that it does not run continually; so for instance, well-water which filters through is *commercium*. He who consumes the water thus obtained by infiltration, even without the proprietor's consent, is not held liable for damages.

Again, water is not considered as having been appropriated where as much enters a basin on one side as escapes on the other.

Every one may enjoy a thing *ex commercium* on condition that such enjoyment causes injury to no one.

None can prevent a person from occupying or appropriating a thing *ex commercium*.

Everybody can utilize the waters of public streams for his lands, and may for this purpose, or for the purpose of constructing a mill, dig canals and ditches or trenches, on condition. however, of doing no injury to any one. Works which cause an inundation, those which completely exhaust a stream or which prevent boats (barges) from floating, are to be interdicted.

Man and beast may drink of the waters not the individual property of any one. The right of "chirb" (*i. e.*, the right to use water for irrigation and for the consumption of animals) of water courses, not public property, belongs to the owners of these streams (courses); any other persons, however, may drink therefrom. Thus no other person than the owner can serve himself of the waters belonging to a community or of a ditch, trench, or well, for irrigating purposes; but he may drink therefrom and even water his animals, provided the number of these be not so large as to damage the water course, the canal, ditch, trench, or conduit; he can likewise draw water therefrom with a pitcher or pail, and carry it to his house or garden.

Those who possess a brook, stream, basin, or well upon their lands, whose waters are renewed by nature, may prevent any one who wants to drink therefrom from entering their property; but if there exists no other water *ex commercium* in the neighborhood, the owners are obliged to either offer the use of their water or allow their lands to be penetrated; and, in case they fail to offer their water, those who wish to drink may enter the property, provided no harm is done thereto by damaging, for example, the edge of the wells or the water conduits.

One of the coproprietors of a common water course can not, without the permission of the others, cut a channel, ditch, trench, or gutter; he can not change his "turn" or share of the enjoyment of the water established *ab antiquo* nor cede such right to a landed proprietor who has no right to the waters of such a river for irrigating his field or watering his cattle. The authorization to perform these acts given by the other coproprietors could be evoked by these latter or by their heirs.

In all contestations touching drinking water or water for irrigating purposes, the rules, regulations, and usages established *ab antiquo* are to be enforced.

The waters of rivers, streams, springs, and other water courses, passing through the lands of a village or a city are the property of the community and must be distributed, as has been the practice *ab antiquo* in such a manner as to secure a supply to each landed proprietor during certain hours, either weekly or fortnightly.

Every owner of land knows the exact time and quantity of water to which he is entitled, and in almost every village there is a civil officer who is charged with the duty of looking after the proper allotment and distribution of the water among all the inhabitants.

As clocks and watches are not commonly in use among the peasantry, the time is measured by various devices, such as hour-glasses, etc.

Besides the Beirut Water Works, noticed under the head of "general remarks," there exist in Syria no irrigation works which supply water against payment, and the Turkish Government has no other interest, nor claims any other right to rivers, streams, springs, and other water courses than to place an increased valuation upon the land irrigated therefrom, and to levy a comparatively heavier land tax.

(5) *Character of climate in irrigated region and nature of soil.*—climate of the coast region is warm and damp. Thermometer r[illegible]ges, the from about 40 to 90 degrees Fah. (in the Lebanon and other mou[illegible]n.

the range is from 10 to 20 degrees less in the winter and from 5 to 15 degrees in the summer.)

The climate in the interior is generally dry, but with greater thermometric range, say 25 to 30 degrees and 90 to 95 degrees Fah. The following table will show the average readings in Beirut during a period of ten years:

Thermometrical observations taken at the Syrian Protestant College at Beirut, Syria, from 1879 *to* 1889.

Month.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.
	°	°	°	°		°	°	°	°	°	°
J nuary	60.92	52.20	61.70	56.70	56.20	54.60	56 60	60.20	55.54	55.30	57.10
February	65.24	58.60	58.00	53.20	56.60	55.30	59.30	59.50	57.52	59.60	60.64
March	62.33	57.81	61.70	62.30	64.40	60.10	62.40	59.70	61.10	64.50	63.16
April	69.26	55.70	67.40	66.00	65.60	66.40	65.80	64.69	67.64	66.50	65.84
May	73.38	70.30	71.70	69.60	70.78	71.16	74.60	70.70	72.36	70.80	71.06
June	81.35	79.50	77.40	76.10	78.65	77.90	78.40	78.90	78.64	76.60	76.12
July	85.79	82.88	82.80	81.40	81.90	80.35	82.50	81.70	82.66	83.75	82.87
August	84.20	84.40	85.60	82.60	83.47	82.00	83.30	83.05	83.97	83.60	.....
September	82.05	81.20	82.90	81.70	81.55	76.30	80.90	81.30	81.00	81.60	.....
October	74.96	77.90	76.50	74.64	76.90	74.20	76.80	75.40	79.77	78.22	.....
November	67.55	71.80	67.40	68.16	67.30	66.82	68.90	65.00	70.84	65.22	.....
December	60.58	59.50	60.80	61.00	60.60	63.80	62.40	61.60	62.50	58.33	.....

No statistics for the interior are known to exist.

The soil throughout almost the entire Vilayet of Syria is of a heavy clayey (argillaceous) nature, which, in drying up, becomes very hard, causing it to crack. In Beirut and other localities the experiment of using sand to improve the soil has been successful, but on a more extensive scale, and upon large tracts, this process would perhaps not prove practicable or feasible.

The character of climate is generally very good in the plains, but better in the mountains; the lands not irrigated are of course the most salubrious; the non-irrigated districts in the "Hauran" (east of Damascus) are considered by far the best, next come the regions to the north, then the Baalbek district, the plains of the "Bekaa" or "Cool Syria," and the districts of "Hasbaya" and "Rashaya." The land around Damascus is all irrigated and the soil is very fertile.

Annual rain-fall or other precipitation.—Along the coast, near Beirut, the annual rain-fall averages about 30 to 38 inches, but in the interior it is much less. One authority estimates it as low as 15 inches, while another makes it from 15 to 50 inches, or an average of 32½ inches. The rain-fall for Beirut for a period of ten years and six months is herewith annexed.

Rain-fall at Beirut, in inches, from 1879 *to* 1889, *observed by the Syrian Protestant College at Beirut.*

Month.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.
January	3.100	9.330	1.320	4.910	12.750	10.639	10.370	5.820	8.910	6.065	6.930
February	2.230	4.205	9.440	10.180	9.251	6.065	4.165	9.865	2.560	6.625	2.885
March	5.600	3.585	5.360	1.325	3.305	3.650	1.640	8.260	1.685	2.745	2.590
April	.540	2.125	2.975	6.250	.900	1.654	3.430	.580	.350	5.158	.840
May	.770	.480	.....	2.570	.350	.547	.050	.420	.375	.170	.100
June	.....	.....	.110	.060	.....	.....	.400	.....	.....	.905	.280
July	.....	.....	.....	.....	.....	.010	.....	.....	.....	.....	.....
August	.....	.....	.....	.....	.290	.035	.....	.....	.....	.....	.....
September	.120	1.013	.765	.....	.....	1.010	.700	.525	.140	.045	.....
October	3.390	.510	1.385	3.125	2.115	1.936	.080	2.205	.....	1.330	.....
November	4.560	1.050	5.540	3.100	15.304	4.350	3.910	3.860	3.065	7.220	.....
December	13.375	9.605	5.760	6.357	6.448	.240	6.910	5.460	10.170	7.885	.....
	32.685	32.343	32.655	37.877	50.713	30.136	31.655	36.995	27.255	38.148	.....

Annual average during ten years, 35.146 inches.

No statistics are kept of the amount of the annual rain-fall in the mountains and the interior, but it is variously estimated at from 15 to 50 inches, according to locality.

The precipitations are: Dew during the summer and the fall more or less plentiful. Very plentiful in spring, sometimes sufficient to ripen the grain, when rains cease early.

In February, March, and April hail-storms are not uncommon. If they occur late they are apt to destroy the mulberry leaves and the vine.

Snow falls on the mountains and in the interior, but no statistics are kept of the quantity.

Generally the country is at least five months without any rain at all, and a month after the last rain-fall the land is dried up to the depth of the roots of the trees, causing a total cessation of all vegetable life, unless irrigation is resorted to. May is the last month in which rain falls, but the copious down-pours really cease with the end of March or beginning of April.

(6) *Antiquity of irrigating systems, etc.*—All the existing irrigation works are of considerable antiquity, some date from time immemorial. On the right banks of the Dog River, about 5 miles north of Beirut, there still exists an old aqueduct, built upon arches and partly cut through the solid rock, running along the river side, which is said to date back to the time of the Roman occupation. The present use is to convey water for the irrigation of a vast tract of land, and to furnish the domestic supply for the village of Jumi, etc.

The ruins of another aqueduct, where the water was conducted over river and dale, are still to be seen in the valley of the Beirut River, about 8 miles above its mouth.

The water-works and conduits of Damascus, Tripoli, Homs, and Hamath are also of great antiquity, and the water is conducted by means of canals of masonry; or where this was impracticable, through earthen pipes and sometimes also through stones scooped out for this purpose.

The ancient canals in the plains of Mesopotamia, between the Euphrates and Tigris are still extant; but they are choked up with the accumulated rubbish of centuries, which, with a little energy and hard work, however, could easily be removed. (See also the report of the "Acca-Haifa" district and the annex to the "notes on irrigation" in the Vilayet of Adana.)

No maps or publications bearing upon the subject of irrigation, etc., exist in the province of Syria.

GENERAL REMARKS.

Under irrigation are usually placed lands lying along the foot of a mountain, from which rivers, streams, springs, or other water-courses flow, and which, by reason of their gentle slope, adapt themselves admirably for irrigating purposes.

In Beirut the area under irrigation extends about 5 miles in one direction and 8 or 9 in another, and the necessary supply of water is furnished by the Beirut River, conducted through five canals. Another strip of varying width and about 12 miles in length runs along the Mediterranean Sea, and is irrigated by the waters of the Dog River, the powerful spring of Antelias and other springs of minor capacity.

The irrigated lands in these districts are planted principally with mulberry trees for the silk industry, besides all kind of vegetables and garden stuffs.

At Tripoli the irrigated lands consist mostly of orange groves, about 5 miles square in extent, which, however, there is no lack, for the river that flows down from Mount Sannin (of the Lebanon range) furnishes an abundant supply, sufficient also for the ancient Tripoli city water works. From Tripoli northward there runs a narrow strip of land between the sea and the mountains of about 1 to 2½ miles in breadth and about 16 miles in length, irrigated from the waters of springs and rivulets which have their sources there. Onions are the principal product of these lands; they are annually exported in large quantities in small sailing vessels. In the interior of the country, wherever there is artificial watering, "durah" or maize is generally grown, and is said to be quite remunerative; but it will not prosper without water.

Between Tripoli and Homs, in the valley of the Nahr "Jabir" (River Eleutherus), large tracts of lands are thus year after year planted with "durah." The crop per acre it has not been possible to ascertain with precision, but it is asserted by an eye witness that the best-looking of these fields would compare very unfavorably with the corn fields in Illinois, for instance, and that they would probably not produce much more than one-half the average yield of American farms. Upon the highlands (plateau) traversed by the river Orontes there is very little irrigation, for the river itself has, in the course of centuries, imbedded itself so deeply that the ancient water conduits can no longer be utilized and new ones have not yet been constructed. The conveyance of water in general is by means of canals or ditches expressly dug for this purpose, where they do not already exist, or where the water does not run of itself; the canals are usually very old, but are not kept in very good repair.

The waters of springs are carried into cisterns or tanks built of masonry, well cemented, which are usually emptied each day; large reservoirs are unknown in Syria, and the maxim among the natives in force is: "That irrigation is only profitable where the water runs unaided by man," that is to say, where condicts and consequently pecuniary outlays are unnecessary. Their ancestors were apparently of a different opinion, judging from the numerous works left by them scattered broadcast over the land.

Of modern irrigation and water works, the Beirut Water Works take first rank; they are the property of an English stock company, which furnishes Beirut with an excellent quality of drinking water at fixed rates, as well as a needful supply for irrigating purposes at reasonable charges.

Sidon a few years since built a pipe line to convey the waters of a spring or springs, situated about 2½ miles distant, into the city; and the municipality of Homs, three years ago, also contemplated the introduction of water works, but the project failed through the opposition of the city of Hamath, which apprehended a decrease and even a scarcity of water for its own supply.

Several efforts have been made by an intelligent and enterprising mechanic, established in business in Beirut, a citizen of the United States, to introduce mechanical and steam power as a profitable means of artificial irrigation. The first attempt made by him was in a region lying between Tripoli and Antioch, a broad plain traversed by a number of rivulets, whose beds, however, had become so deep that canals could no longer be made serviceable as conduits or conveyances of their waters, especially as there was not sufficient fall or headway.

A rich Arab who had seen the irrigation works in Egypt, conceived the idea of applying them practically to his lands situated in the dis-

trict above mentioned and went so far as to order a machine of five horse-power. The pump was a "pulsometer" with 4-inch pipes, and the water had to be raised to an elevation of about 30 feet. The pump was guarantied to lift 750 litres or 166⅔ gallons per minute; it worked for forty days, fulfilled all its expectations, and would have been capable of irrigating an area of at least 80 acres in extent; but it appears that the fuel proved too expensive, wood being scarce and coal very dear, so that the experiment has been for the present at least abandoned.

A second attempt was made in the spring of this year in "Hazmyeh," in the neighborhood of Beirut, and notwithstanding that the water had to be elevated fully 130 feet, proved entirely successful.

The water is first raised about 10 feet from a well dug close to the Beirut River, by means of a cylindrical pump worked by a steam motor of three horse-power, and then forced through iron pipes along a hill to the height of 120 feet into a basin holding about 90 cubic meters, 3,543 cubic inches of water, for irrigating purposes. The basin can be filled in about six or seven hours, and the capacity per hour therefore is about 14 cubic meters, or 551 cubic inches. The investment seems to have proven an entirely satisfactory one in every respect.

A "Hallonday" wind motor has also been in operation near Beirut for over four years, which raises water to a considerable height and works satisfactorily. In general, irrigation as practiced in Syria does not entail any greater or other expense than the cost of maintaining the canals, conduits, etc., in good repair; but this, it must be repeated, is not always done.

Irrigation, as has already been shown, is regulated entirely by usage and well established rules, and every parcel of land has a right to the use of water for certain well fixed length of time. For instance: A small proprietor near Beirut has five acres of land; every Friday he can take as much water during six hours as he may need to thoroughly saturate his land; if he fails to take advantage of his privilege, he simply forfeits it without being indemnified therefor. Where water is scarce, as in many places in the mountains, it is often divided into hours and even fractions of hours, and good care is taken that no one receives or takes more that his allotted share. The sole owner of a spring—a rare occurrence, however—may of course use the water thereof at his own pleasure.

It is worthy of remark that in Mount Lebanon the waters of every spring, no matter how limited its capacity, is caught up into cisterns of good solid masonry, and is utilized for irrigating and domestic purposes, and no matter how steep the mountain sides or how poor the soil, the smallest available and tillable space is planted with onions, vegetables, marrow, or egg plant, and three and sometimes even four crops are thus produced each year.

The lands in Mount Lebanon are exceptionally well kept, and the population is principally composed of Christians (Maronites and Greeks, etc.), and Druzes, who are quite prosperous, and whose destinies are presided over by a Christian governor-general.

If the foregoing notes do not contain much of practical value or importance for the purposes intended, they may at least serve to impart some interesting if not useful information regarding the people of the oldest country, and of their ancestors the Phœnicians, which may not be generally known in the United States.

ANNEX B.

IRRIGATION, ETC., IN THE DISTRICT OF ACCA-HAIFA (SYRIA).

From materials furnished by Consular Agent J. Schumacher and Civil Engineer G. Schumacher.

The Acco-Haifa district and the region of the Hauran probably offer little in the way of irrigation that will prove of much value or interest, for the purpose of the State Department would appear to be to secure information of a practical character on a larger scale.

Interrogatory No. 1, "areas of land under irrigation," etc., of which the succeeding five interrogatories are merely an elaboration, can be summarily answered by the statement that there practically do not exist in Gallilee, in Nablus, or in the Jordan Valley any irrigation works in the full sense of the word as understood in the United States, and that land under irrigation in those districts is almost wholly unknown, forming but an infinitesimal—probably not more than the two-hundredth—part of the whole arable land.

In the Jordan Valley, on the Hûlé (sea of Merom), north of the Batîlôa and south of the Lake of Tiberias, also in the Wäd el Arab and Wäd el Tanjibe, the Bedouins irrigate small parcels of about 10 to 60 acres, upon which "durah" (maize) is grown, yielding annually two and even three crops. This result is due in part to the exceptional climate of the Jordan Valley with its tropical heat—a perfect hot-house—to the rich alluvial soil washed down from the basalt mountains, and also, perhaps, chiefly to the great abundance of water in the Jordan and Huromax (Arab, Sheri'al el Menädise); whereas the higher regions of Palestine and the littoral of the Mediterranean Sea are comparatively too poor in water supplies to enable their inhabitants to irrigate their lands to any great extent.

The irrigation process in all these districts supplied by water is of the simplest and most primitive character. In the early morning or shortly before sunset, young Bedouins in a semi-nude state may be seen roughly constructing from stones and earth a temporary dam to obstruct the waters of a stream or wadi (valley) while others provided with broad hoes dig little ditches, through which they lead the overflowing waters to be distributed over the parcels it is intended to irrigate, allowing the water free course in the lower lying lands, thus inundating or rather completely setting them under water. These manipulations are of daily repetition; the dams have to be regularly rebuilt, for the pressure of the water causes their daily destruction, and it is interesting to watch with what assiduity and perseverance these Bedouins are continually remaking and renewing the little ditches or canals which need their unremitting attention.

Reservoirs, basins, tanks, etc., do not exist, and the systems in practice here will therefore scarcely commend themselves to the inhabitants of more progressive countries.

Here and there, along the sea of Tiberias, remnants of ancient Roman irrigation works may be met with; but they are in such a deplorable state of dilapidation that of their original construction only a catchment basin remains near the head of the spring and a portion of a conduit (in masonry) is also yet in a fair state of preservation. The original character or the practical application of these ancient works can, however, no longer be established or recognized; for the Arabs not only made no use of them, but allowed everything to fall into decay and ruin, preferring the antediluvian ways of their own ancestors to the innovations of the Roman intruders.

In response to interrogatory No. 4, it may be said that "the system of water distribution," etc., depends wholly upon local custom as regulated among the different communities themselves. If several inhabitants of a village, for the purpose of irrigation, desire to utilize a spring in common they will use and distribute the waters thereof in conformity with local tradition as sanctioned by the municipal authorities; such at least is the custom or practice in this vicinity. In all cases the proprietary rights of a village spring remain vested with the community, and the spring itself can never be sold.

The climate (question 5) in the irrigated districts of the Jordan Valley and in the arable lands bordering the Lake of Tiberias is, on the whole, rather insalubrious, engendering malarial fevers caused by the evaporation (exhalations) during the heat of the day and the rapid cooling off at night; in other words, owing to the sudden change and wide range of temperature.

For habitation, irrigated districts are carefully avoided in these parts, and as a rule only negroes are capable of withstanding the deadly effects of the miasmata.

According to careful observations and measurements in Haifa during a period of twelve years, the Phiviometer registered from 19.69 to 34.04 inches per year; last year it reached 33.86 inches. The yearly average, however, may be taken to be 26 inches.

A draw-well in almost universal use in these regions, and by far the most practical and cheapest method of irrigating small parcels and gardens, is the "Hanani," a sketch of which in its improved form as in use by the Haifa German-American Colony is annexed herewith.

The "Hanani," as used by the natives, is of a much more imperfect and primitive construction than that of the colonists.

It may be worked by either donkey, mule, or horse (wholly unattended), and can be utilized to a depth of 150 feet. The size of the well buckets decrease in proportion to the profundity of the well to allow the "Hanani" to be worked by a single animal of either of the above species.

The amount of water raised diminishes in consequence with the increasing depth of the well, and the following table will serve to illustrate the practical results observed:

Place of observation.	Depth of well.	Amount of water raised per hour in gallons.
	Feet.	
Haifa	25	5,200 liters * = 1,144½ gallons.
Haifa	30	4,000 liters = 889 gallons.
Gaza (Palestine)	146	2,500 liters = 555½ gallons.
Sea of Merim	15	6,500 liters = 1,444½ gallons.

* Four and a half liters equal 1 gallon.

Of course the employment of steam would greatly increase these figures.

These quantities will vary according to the working capacity of the different animals employed, and the above figures were obtained by well-nourished animals, resting one hour after every three hours of consecutive work. The principal basin is generally replenished in from six to eight hours. It is constructed of masonry and well cemented, and ordinarily was 20 feet in length, 18 feet in width, and 7 to 8 feet in depth.

The main basin empties itself into a smaller one, 4 feet square by 2 feet deep, from which the water is conducted directly into the main irrigating canal, made of masonry, and situated in the most elevated part of the land, which feeds the numerous little ditches that distribute the water over the garden or field to be watered. The "Hanani" is of great durability and seldom needs repairs, especially if the water is free from saline particles; it is of the simplest construction and can be handled by the most inexperienced person.

REPORT ON IRRIGATION IN THE CONSULAR DISTRICT OF MERSINA (ASIA MINOR), SYRIA.

In the Vilayet of Adana, Syria, there are about 4,740,000 acres of land cultivable, but no irrigation works.

In the plain between Mersina and Adana there are about 400,000 acres irrigable, and between Adana and Missis about 350,000, through which there are three rivers, the Cydnus, the Sarus, and the Pyramus flow, but up to the present there are no irrigation works. The consequence is that for the last four years part of the crops has been completely destroyed, and what has succeeded could not be produced at prices to compete against the American and Russian markets in Europe.

The Turkish Government, on the pressing demands of the agriculturists, have recently taken the matter of irrigation in hand, and His Excellency the Vuli Sirri Pacha asked me to assist him in making the necessary surveys and plans, and I have just handed him the plans to irrigate a portion of the plain from Taraus towards Adana for a distance of about 15 miles, which can be done at a very small cost. The other parts of the plain, however, towards Adana and between this latter and Missis will cost about £400,000 to irrigate properly, and although this sum would be comparatively nothing compared with the results, yet the Government, in order to avoid this outlay, want to try to make these irrigation works "a la Turque" if possible, but unless they are carried out by a competent company I am afraid it will be a failure.

The principal crops grown are cotton of very short texture, about 16,000 tons; wheat and barley of second quality, about 25,000 tons; sesame seed of first quality, about 4,000 tons; raisins of very inferior quality, about 4,000 tons.

The soil is partly red and partly sandy. Rain-fall averages 22 inches per annum.

The antique irrigations simply consist of the cultivators in the immediate neighborhood of the rivers and mill streams taking advantage of the water passing their

NOTE BY THE BEIRUT CONSULATE ANNEXED TO THE REPORT OF THE "MERSINA CONSULAR AGENCY."

In olden times the vast plains of the Vilayet of Adania, Syria, were entirely irrigated by the rivers that pass through them. The Romans were in the habit of damming out the required quantity from the waters of the Djihoun, Seihoun, and Cydnus, and, conducting it to the foot of the mountains, form a high level on both sides of the rivers, along the surface of the ground, accumulating earth on both sides of its banks, making in this way a wide, high canal, extending from the mountains on both sides of the rivers in various directions to the sea. The farmers had thus the water within their reach and could easily, and at little expense, by means of subsidiary canals, conduct any portion of it to irrigate their lands.

These long and ancient canals, extending from the foot of the mountains to the sea in all directions, are still extant, and need but to be freed from the rubbish that centuries have accumulated to be again serviceable.

REPORT FROM HENRY GILLMAN, U. S. CONSUL, JERUSALEM, ON IRRIGATION IN PALESTINE.

With the exception of Jaffa and its immediate neighborhood, there is no part of this consular district in which any extensive and systematic attempt at irrigation according to modern methods is made.

THE JORDAN VALLEY.

In the Valley of the Jordan, which contains from 500 to 600 square miles of some of the richest land in the world, and which is never visited by frost, being from 700 to 1,309 feet below the level of the Mediterranean Sea, and where, with its semi-tropical climate and facilities for irrigation, several successive crops, may be produced annually, only the most feeble and primitive methods of conducting the necessary water to the few and ill-cultivated fields are followed. This unique valley, capable, with proper agricultural treatment, of sustaining an immense population, has no settlement worthy of the name. The wild Bedouin Arabs range throughout its length and breadth, and in defiance of the Turkish Government, which have in vain attempted to drive them out, come and go at their own free will.

Small fields, gardens, or patches of ground are here and there cultivated in the neighborhood of some stream having its source in one of the perennial springs of the region. From such a stream the water is conveyed in shallow drains or ditches to wherever required, and is carried through the fields or gardens by still smaller channels, the water being shut off or let on simply by the action of the foot, opening the tray inlet, or blocking it up with a few pebbles or masses of clay, as may be desired. This is a habit as old as the oldest writings, and of which mention is made in the Bible. "Where thou sowest thy seed, and waterest it with thy foot, as a garden of herbs." (Deut. 11, 10.)

Only the common farm crops are cultivated; but they are of specially exuberant growth.

At Nablous, or Ancient Shechem, or Sychar, similar methods in general are followed. The comparatively few fields and gardens are well watered from the abundant streams which have their rise in the Mounts Gerizim and Ebal, making it a spot of beauty in the midst of wild and unreclaimed surroundings. In one or two instances here there have been made some efforts at a more enlightened system of irrigation, the water from the clear and copious springs being conducted by aqueducts of stone masonry, and more satisfactorly supplied. The result in the

luxuriant gardens, in which most of the various kinds of fruits and vegetables suitable to the climate are found, testifies as to what might be accomplished were more intelligent, systematic, and thorough measures adopted.

Throughout Palestine a very little water produces a wonderful result. The soil, naturally fertile, immediately responds to the effect of the periodic rains. The bursting of the land into bloom after the first heavy showers of the rainy season is a sight never to be forgotten. The hillsides and valleys that through the dry season had lain burnt up and barren, like a calcined bone, are suddenly, as if by miracle, turned into a garden of the most brilliant blossoms; the scarlet ranunculus and anémone, pomegranate, and many other flowers and shrubs only known to us in cultivation, "making the wilderness and solitary place rejoice and blossom as the rose."

THE KING'S GARDEN, JERUSALEM.

In the valley of the Kedron, on the southerly side of Jerusalem, is the king's garden, which dates back to the time of Hezekiah, if not to that of Solomon. It is mentioned in Nehemiah (3, 15) where it speaks of "Siloah by the king's garden."

The few acres which are at present under cultivation here are irrigated in the usual simple manner. The source of the water supply in the celebrated pool of Siloah, or Siloam, a reservoir 53 feet long, 18 feet wide, and 19 feet deep, which is fed through a subterranean conduit by the overflow of the pool of the Virgin, an intermittent spring about one-quarter of a mile to the northward. The water is conducted from the former pool partly by underground drains, regulated by the most primitive of sluices into smaller channels in the direction required, where still finer ramifications or branches distribute it to the drills or rows in which the crop is planted; much as in the other instances mentioned, and with as little regularity or system.

In these garden plots all the ordinary vegetables and many kinds of fruits are produced in good quantity and of fair quality. And up the terraced slopes, even to the very walls of Jerusalem, some of the largest cauliflowers come to perfection, and are in the market in the months of February and March. This vegetable sells at the rate of three heads for 12 cents.

There is no special regulation as to the use of the water other than that of the most patriarchal kind, the owners of the adjacent land having free access to the pool for all requisite purposes, including household uses, and the watering of their flocks and herds. Much of the water is also brought into Jerusalem for sale in goat skins.

KING SOLOMON'S POOLS AND GARDENS.

About 8 miles to the southwest of Jerusalem are the wonderful pools of Solomon; while, below them, in the narrow valley of Urtas, lie the renowned gardens of the wise king, except the garden of Eden, I suppose the oldest recorded gardens in the world. These works are mentioned in Eclesiastes (2–46) as follows:

> I made me great works; I builded me houses; I planted me vineyards; I made me gardens and orchards, and I planted, in them, all kinds of fruits; I made me pools of water; to water therewith the wood that bringeth forth trees.

There is little doubt, too, that the scenes depicted in that beautiful oriental love-song—"The Song of Solomon," found here their original.

Josephus also speaks of this place: "Very pleasant it is in fine gardens, and abounding in rivulets of water," and tells us that Solomon was wont to visit it frequently, describing him as driving out there in the morning sitting on high in his chariot, clothed in white, and surrounded by his handsome mounted guards, all of great stature, and in the flower of manhood, arrayed in Tyrian purple, and in armor, their long hair sprinkled with gold-dust. It would be difficult to overestimate the noble character of those remarkable works, especially considering the periods in which they were constructed.

The pools consist of three enormous reservoirs, partly cut in the rocks, partly built of massive marble masonry. Their dimensions are as follows: The upper pool, 380 feet long; breadth at east end, 236 feet; at west end, 229 feet; depth at west end, 25 feet.

The middle pool, which is distant from the upper pool 160 feet, is 248 feet long; it is, at east end, 250 feet broad, and at west end, 160 feet, while the depth at east end is 39 feet. The lower pool, 248 feet eastward of the middle pool, has a length of 582 feet; a breadth at end, of 207 feet, and at west end, of 148 feet; and a depth at east end, of 50 feet, having sufficient capacity, as Dr. Thomson has said, "to float the largest man-of-war that ever ploughed the ocean." Each pool overflows successively by regulated sluices into the next below it, in the order here given, the last pool emptying its superabundant water into the valley.

Those venerable structures are at the present time in an excellent state of preservation. They are said to have been repaired by Pontius Pilate, which would be about 1,855 years ago.

The source of the water supply is the sealed fountain of Solomon, at the foot of a hill a short distance west of the upper pool. This fountain is always kept locked, hence the name. A flight of twenty steps descend from an arched doorway into an underground vaulted chamber, where four streams of pure and cool water converge. This fountain also afforded in former times a constant and abundant supply of water to Jerusalem, a goodly stream being conveyed by the carefully and skillfully constructed stone aqueduct of Solomon, which demonstrates that they understood at that early day the principle of the syphon, having introduced it into the Holy Temple inclosure.

About two years ago, the less ancient Saracenic aqueduct being put in repair, the water was once more brought into the site of the temple area, and into the so-called Fountain of the Cup, which stands between the Mosque of Omar and the Mosque Al Aksa, and doubtless marks the site of the brazon laver made by Solomon for the ablution of the priests in their sacrificial worship.

But the aqueduct soon again lapsing into disrepair, the water is, at present, barely conveyed in small quantity as far as Bethlehem, of which town it is the principal supply.

Of the 75 acres of land below the pools, in the valley of Urtas, 25 are under cultivation, and are irrigated.

Independently of the pools, the garden lands of the valley are also largely watered from a separate copious spring, which has its rise in the side of the mountain and at the foot of the village of Urtas. The soil is a red clay, exceedingly fertile, and to this day the finest fruits and vegetables in the Jerusalem market come from these gardens.

Of the fruits produced may be mentioned apricots, peaches, nectarines, apples, prunes, plums, citrons, lemons, pomegranates, mulberries, figs, and grapes. The vegetables include peas, beans, beets, ockra, egg-plant, onions, leeks, garlick, potatoes, turnips, cabbage, cauliflower,

carrots, cucumbers, pumpkins, vegetable marrow, tomatoes, and radishes.

About two-fifths of the land belong to three Europeans, and the remainder is owned by the native Syrian fellahin (peasants).

The distribution of the water is regulated by the old custom or system of "fassels;" a night and a day forming a "fassel." Each family owning land there knows, from time immemorial, its respective rights and share in the "fassel" of water. Some have an entire "fassel," and again the same is divided among the different members of a family to irrigate their respective shares of land. The water is carried from one plat to another by drains in the usual simple manner already described. The Europeans who own land there have made, however, a cemented conduit to convey their share of water into their ground. No statistics are obtainable, none ever having been kept, as to the duty of water per acre.

No special rent or fee is paid for the water used, nor are there any charges on the land in connection therewith, the only payments made being the usual government taxes, the werko (land taxes) and ushur (titles).

Solomon's Park, the Sealed Fountain, and the Aqueduct are public property, and are under the control of the Turkish Government.

JAFFA AND ITS ORANGE GROVES.

The town of Jaffa, looking down from its pleasant elevation, on the one side on the deep blue Mediterranean and on the other on its multitudinous palms and odorous orange groves, may well be considered entitled to its name, which, softened in the Arabic pronunciation to Jaffa, means "beautiful."

The orange groves and gardens and their system of irrigation, though they have been greatly extended within comparatively recent times, have unquestionably an origin of quite respectable antiquity.

(1) The area of land under irrigation at Jaffa would exactly include the space occupied by its orange groves, being nearly one-third of the cultivable ground belonging to the community, that is, of 9,000 acres of cultivable lands about 3,000 acres are under irrigation.

The orange and the lemon are the chief crops; but other fruits, such as citrons, limes, peaches, apricots, grapes, pomegranates, and melons, and all the ordinary garden vegetables are also produced in abundance, and of fine quality. The vine especially is of late receiving much attention, and within the last few years extensive vineyards have been planted. Neither the vine nor the olive, of the latter of which there are many groves, require any water other than the usual rain-fall.

The superiority of the Jaffa orange is world renowned, whether its size, juiciness, or flavor is considered.

In an average season oranges and lemons, together with other fruits and vegetables, to the amount of $335,000 have been exported from Jaffa. Besides this is the immense home consumption, of which there is no record.

(2) The sources of the water supply are wells which are fed by underground springs.

(3) The engine in use for raising the water is in every case without exception the so-called bajara or bayara, a modern machine of the most simple construction, driven by horse or mule.

Its principal parts are a whim-beam or capstan, with horizontal wheel attached moving a vertical wheel connected by shaft with a third wheel,

which carries at its circumference a chain of pendant reversible buckets.

A pole inserted in the whim-beam is fastened to the horse or mule, with the monotonous circuit of which animal the entire machine is set in motion, the wheel with buckets revolving in the well dipping up the water and emptying it into the conduit or tank. The tanks are usually close to the wells, and are cemented basins, built of stone. They are filled during the day, the water being distributed from them, through the various channels, during the night in order that the loss by evaporation may be reduced to the minimum.

There are about seven hundred of those bajaras at work at Jaffa.

(4) The system of water distribution, being entirely under private control, is governed by neither law nor regulation.

The quantity of water used per acre during the season of twenty-three weeks or one hundred and sixty-one days is 2.300 cubic meters, at a cost of from 20 to 25 cents per diem. Thus, for instance, the average expense for irrigating an orange-garden with an area of 5 acres would be for one hundred and sixty days, at 20 cents, $160. The value of the crops might be estimated at from $500 to $700.

(5) Owing to the peculiarity of the climate, the orange groves are obliged to be watered during the summer months, or rather during the "dry season," when no rain falls; that is, from May till October or November. The rain-fall in the winter months, or say from November till May, varies from 17 to 30 inches. The average temperature is, in the day-time, from 70 to 90 degrees Fah.; during the night from 53 to 56 degrees.

The soil in the orange groves is of mixed clay and sand, with rather more of the latter than of the former. Is exceedingly fertile, and is particularly well suited to the orange.

(6) As to the antiquity of the system of irrigation, the close resemblance of the bajara to the Spanish "moria," has induced many persons to imagine its being introduced here at some early period from Spain. But as the family likeness of these wheels to the ancient Persian wooden water-wheel is equally great, and as the Crusaders, in the eleventh century, are reported to have found the orange-tree (*Citrus aurantium*) already in Palestine, the actual system of irrigation may as well belong originally to this country, or to the East, and may have been introduced from Persia.

GENERAL REMARKS ON THE CLIMATE.

In addition to the facts already given respecting the climate of Palestine, I add the following remarks: It is evident from the statements of history, both sacred and profane, as well as from other testimony, that this country in former ages was not only under a more general and thorough state of cultivation as regards its agricultural districts, but also that it possessed extensive tracts of forests, which have long since disappeared. Consequently its rain-fall was more favorably regulated, being more equable in its distribution. The result would naturally be not only the temporary advantage of the improved growing crops, but the enrichment of the soil and the permanent benefit of the land.

At present, seasons of almost tropical rain are followed by the long dry period in which not a drop of rain falls, and nearly every green herb perishes and burns up for the lack of moisture. Swept by the resistless torrent of the "rainy season," the higher lands are stripped of their soil and entire districts are seen in which the bare and barren ridges of rock crop out like the bones in the skeleton of some gigantic animal.

The phenomenon of the "air cushion" is seen here to perfection. Before a rain sets in it generally takes several days of incubatory preparation before the result comes. Great clouds roll up and cover the entire heavens with their dense masses; but in vain they attempt to discharge their contents, or if they succeed in dissolving, the thirsty atmosphere drinks up the moisture before it ever reaches the earth; and this must continue until the intervening strata composing the "air-cushions" are sufficiently saturated to permit the rain to fall through, which then occurs in a violent and often injurious downpour. Deprived of the gentle mediation of the growing crops, and especially of the forests, which would have established the proper relation and a just equilibrium, through their continual evaporation, the parched ground languishes for the rain that is denied it, or that, when given, comes in almost an unwelcome shape.

During the serious drought of 1887 and 1888 this phenomenon was seen in an extreme degree, weeks, and even months, passing without adequate rain, though the greater part of the time the heavens were dark with clouds.

The intervening unsaturated "air cushion" drank up the contents of the clouds, as already described, so that little or no rain could pass through it.

It is thought that the agricultural colonies established here within recent years have already begun to produce a perceptibly beneficial effect in this direction, but probably it is too soon yet to look for any decided change.

REPORT OF W. C. EMMET, U. S. CONSUL, SMYRNA, ASIA MINOR.

There is no irrigation practiced in this or any other district of Asia Minor, except in kitchen or fruit gardens in the neighborhood of large towns.

In these cases the supply of water is from wells on the premises, and the machinery used is a large wheel-bucket pump, worked by a horse.

These wells are of various depths and the supply of water utterly fails in some during long-continued droughts.

No water-works or artificial lakes are to be found anywhere, although there are numerous rivers, streams, and lakes which could be adapted to overcome the effects of the dry season, which usually lasts from five to six months.

These water sources belong mainly to the Government, in some instances to religious communities (mosques), but the right to use the same can be obtained at moderate cost.

In this section the yield of crops depends on a merciful Providence in withholding rain during the growing and harvesting seasons; the ingenuity or industry of mankind takes but an insignificant part in producing large crops.

Although the largest revenue to the Government is derived from tithes on agricultural products, the over-taxed peasantry labor under great difficulties and receive no encouragement or assistance from the Government.

The area of irrigated land does not amount to 1 per cent. of the arable land in this province.

The annual rain-fall rarely exceeds 26 inches per square foot, in fact, that is considered an ample supply.

The proportion of irrigated surface is so small that no perceptible effect is made on the climate of the district. The soil is mainly a sandy loam.

THE INDIAN OCEAN.

REPORT FROM ALEX. R. WEBB, U. S. CONSUL, MANILA, ON IRRIGATION IN THE PHILIPPINE (SPANISH) ARCHIPELAGO.

Owing to the numerous streams that rise in the mountainous districts and flow through the low lands to the sea, as well as to the copious rains, which will average 100 inches during the year, irrigation is seldom necessary in the Philippine Archipelago. When it is resorted to the most primitive methods are followed. If the rainy season commences later than usual the rice lands are sometimes irrigated by damming the mountain streams and turning the water over the paddy-fields through small channels, and in some cases the very old-fashioned chain-bucket windlass is used. This is a simple contrivance, composed of a number of small, water-tight boxes, formed into an endless chain by means of stout rope or leather bands, which run over a roller anchored in a river or creek, and a windlass on the bank turned by hand or cattle power. This is also used, in some cases, during the dry season on the lands where "zacate" or swamp-grass, which is fed to horses and cattle, instead of hay, is raised. On the low lands near the coast, where the rivers and creeks rise and fall with the ocean tide, sluice-ways and gates are sometimes used to flood the zacate lands during the dry season. These fields are seldom more than an acre or two in extent, and a comparatively small quantity of water is needed to flood them. The sluice-way is usually about 1 foot or 18 inches square, and when the tide rises the gate is left open until the required amount of water has entered, when it is closed and remains so until more water is needed.

On an estate belonging to the Dominican Fathers between Calamba and Bruan, and on another owned by the Augustinian Fathers near San Francisco de Malabon, both situated on this island (Luzon), some irrigation is done during the dry season by turning aside the mountain streams on the zacate land, and near Carite, about 27 miles northwest of Manila, a small stream is conducted through an iron pipe for about one hundred yards for the purpose of irrigating the paddy and zacate fields when water is needed. As a rule, however, the only irrigation received by the rice fields is from the rain-fall. The rice is planted about the commencement of the rainy season and is harvested shortly after the opening of the dry season, which seldom continues more than three months. The atmosphere is always moist at night, and heavy dews keep the earth damp and prevent the vegetables from drying up.

There is no portion of the archipelago where irrigation is conducted on an extensive scale and no means are known here by which the total area can be ascertained. All the irrigation is done on small patches of land and at private expense.

There are no storage works nor any general system of water distribution for irrigation. The Spanish water laws are in force for the government of the water supply used for household and street-sprinkling purposes in Manila, but among the general laws there are none upon the subject of irrigation.

AUSTRALIA.

REPORT FROM G. W. GRIFFIN, U. S. CONSUL, SYDNEY, ON IRRIGATION AND WATER CONSERVATION IN NEW SOUTH WALES.

There is perhaps no question that has attracted so much general attention throughout New South Wales and the other Australian colonies as that of irrigation and the reclamation thereby of arid lands. Royal commissions have been appointed in the colonies for the purpose of conducting inquiries in regard to the best means for distribution and conservation of water. The peculiar physical formation of this great island continent, as shown in the absence of lofty snow-clad ranges of mountains and great rivers, had added an element of difficulty to the inquiries of the commissions.

In my report entitled "Irrigation," transmitted to the Department of State in 1887, I endeavored to summarize the results of the New South Wales water commission inquiry. My report was republished by the Government of this colony in book form, and a copy will be found along with the publications I send herewith under separate cover, a detailed list of which will be found at the end of this report. Since that date the commission has made a final report, and a copy of this is also forwarded in the same manner.

It will be seen from the final report that a considerable portion is taken up with a discussion of the various plans proposed for the utilization of the waters of the rivers Murray and Darling. The following are the conclusions at which the commission arrived as the result of their investigations:

(1) That on water conservation mainly depend the prosperity and the development of the whole extent of the central and western divisions of this colony, and that though less required in the eastern division, it will add in many places there also in an important degree to the productions, and therefore to the value of the land.

(2) That as the land-holders, as a general rule, are quite equal to the task of providing sufficient water for the stock which the land can carry under present conditions, Government works for supplying water to stock are required only on a limited scale, and generally only on traveling stock routes.

(3) That the great object of water conservation in this colony, and particularly in the country west of the dividing range, is irrigation.

(4) That the purposes for which irrigation is chiefly required are (*a*) to provide fodder and grain for horses, cattle, and stud sheep; (*b*) to afford supplies to be kept in reserve for saving stock of all kinds in bad seasons; (*c*) to produce fruit, vegetables, and miscellaneous crops, and (*d*) to increase generally the productive powers of the land.

(5) That any well-considered and properly executed project for irrigation in the country west of the dividing range would afford a good direct return on the capital invested, and would be a distinct benefit to the colony at large.

(6) That legislation on the subject of water rights is a matter of pressing necessity, both to protect the rights of the state and to foster and encourage local and private enterprise.

The severe droughts in Australia, recurring periodically, constitute the most serious difficulty against which the people have to contend.

AREAS OF LAND UNDER IRRIGATION.

Irrigation works in New South Wales have only been carried out on a very small scale by private enterprise by the squatter, a term applied to the occupiers of land in Australia, to provide fodder for working and stud stock, and by the culturist for orchards, vineries, and gardens. I am informed by Mr. A. Pepys Wood, civil engineer, that no attempt has been made to irrigate agricultural holdings as such. The efforts, however, that have been made, limited as is their scope, have been found valuable, not only to the parties directly concerned, but to the public, as showing the wonderful results to be obtained from the soil and climate of the western districts, especially when a certain supply of water is available for watering. When this supply has been constant the results are said to have amply repaid the owners and to prove the large profits to be derived from such works if carried out judiciously on a lawful scale.

The area of irrigated land in New South Wales is at present so small as to be scarcely worth taking into consideration. It is true enough that a few individuals have irrigated portions of their lands at their own expense, but the absence of any well-defined laws on riparian rights goes far to prevent the people from utilizing the surplus waters of the various rivers and creeks. The main dependence of the Australians, thus far, for their water supply has been on dams, tanks, and wells.

In the Lachlan district a number of farmers have practiced irrigation on a small scale. Mr. T. Towser erected a pump about a mile from Forbes where there is a bend in the Lachlan River. The plant cost about £600 ($2,920). The plant consists of a six horse-power engine, a five-inch centrifugal pump, and 75 feet of piping.

The pump lifts the water to a height of 38 feet and has power to bring up 2,500 gallons of water per hour. Mr. Towser, during the drought of 1888, irrigated 12 acres of vines and fruit trees. He flooded the land four times. To water half an acre of land necessitated the use of the pump nine hours and he estimated that the 12 acres absorbed 2,600,000 gallons of water. Mr. Towser, speaking of his experment, said:

> I could hardly get props enough to keep my trees from breaking down under the very heavy load of fruit, while other orchards not irrigated, in the district, yielded a very small quantity of fruit.

The Lachlan soil, with the help of irrigation, will grow the finest fruit in the southern hemisphere. The fruits produced are numerous and include many varieties of oranges, lemons, citrons, pears, peaches, apricots, nectarines, quinces, figs, loguats, grapes, and strawberries. The fruit, which had to be sent a long distance to market, is described as unsurpassed in quality and, notwithstanding the high cost of freight and poor facilities for handling it, realized a good profit. It is proposed to reduce the cost of irrigation on this property by using a 10-inch instead of a 7-inch pump. Irrigation is used in the same district by the Messrs. Eadles & Co., who have a 9-inch pump for irrigating about 800 acres of grass land suitable for high-class stock, also a 7-inch pump is used for a smaller tract. Both pieces of land have carried eight to ten sheep to the acre, while other stock farms, not irrigated, were literally ruined by the drought.

It may be well to mention that Forbes is a town on the river Lachlan, 250 miles west of Sydney. It has a population of about 3,000 inhabitants and it is rapidly becoming a center for the trade of a large

section of the country around. The town is supplied with water filtered from the Lachlan, laid on in pipes at a considerable cost. The district contains about 10,000 inhabitants and carries 1,000,000 sheep, 10,000 horses, 5,000 cattle, and 2,000 pigs. In one year 8,315 acres were planted in wheat and produced 100,519 bushels.

Mr. Gatenby, about 25 miles from Forbes, irrigated in 1888 90 acres of land, which was laid down under grass, lucern, maize, and orchard. He used a 6-inch pump and he estimates the cost of irrigation at £2 ($9.73) per acre.

Mr. Gatenby stated that with a larger pump he could reduce the cost to about 10 shillings ($2.43) per acre. He found that lucern only required half the quantity of water necessary for ordinary grass. His grass land, which was watered once a month, carried eight sheep to the acre, and his maize land produced 100 bushels to the acre.

I learn from the third and final report of the royal commission on the conservation of water in New South Wales that at Windbar 7 acres yielded 30 tons of lucern hay per annum, under irrigation, at a cost of £3 ($14.60) per ton, during a drought when chaff delivered cost £23 ($111.93) per ton. It was estimated that the experiment with irrigation on his property resulted in a saving of £1,000 ($4,866) in the year.

Again, it is stated that at Tapio 18 sheep to the acre were maintained in splendid condition on a patch of 22 acres of irrigated land, while on the surrounding country 13 acres barely sufficed to keep one sheep alive; and further, Mr. N. Sadlier, of Albemarle, stated that on an area of 3 miles square, irrigated by the flow of flood-waters over low-lying land, he kept 8,000 sheep in the middle of summer and had a good lambing, while the same land, when not irrigated, did not carry 1,200 sheep. The only difficulties which seemed to present themselves were in regard to maintaining a permanent supply in the river to make irrigation possible during the time most needed—a prolonged drought—and the want of practical knowledge to employ the methods of irrigation.

It will be well enough to mention here that the farmers who have tried irrigation are highly gratified with the results, and in most cases their profits have doubled and trebled more particularly where the irrigation was used in the natural grasses of the country and with lucern, maize, and sorghum.

I could give many instances where irrigation has been adopted with unvarying success, but the areas are mostly small, probably not exceeding a total of 50,000 acres. In the colony of Victoria, however, very large areas are being rapidly placed under irrigation.

SOURCES OF WATER SUPPLY.

The sources of supply of water for irrigation are from rivers, creeks, tanks, and wells. The shortage of water supply extends over such vast areas of country as to be a source of astonishment that no well-directed effort has been made to conserve at least a portion of the supply falling during the tropical rains, especially in the northern territory.

With reference to the works situated on the rivers, the requisite supply of water has been obtained by pumping. For this work the centrifugal pump is generally used, though in some cases, such as for orchard and garden irrigation, direct acting pumps or the "Blake" or "special" type are used. It is said that none of the western rivers, except the Murray, can be relied on for irrigating large areas, unless works be constructed to impound an artificial supply. Certainly with some rivers,

such as the Namori the supply in long-continued dry seasons is even inadequate for the small areas being dealt with at the present time.

The discoveries of subterranean fresh water north of the Darling River and the immense supply being obtained from some of the artesian bores point to a near development of irrigation on a more or less extended basis in that region. In the country south of the Darling the water in nearly all the wells that have been sunk is said to be brackish, which, together with the mineral matter contained in it, is unsuitable for irrigation. Were this not the case the depth (averaging 100 feet) would preclude its use for this purpose except when drawn by windmills, as fuel for motive power in most places where these wells are is reported to be scarce and expensive. It remains to be proved by boring whether at a greater depth an artesian supply of fresh water can be obtained; but as the geological formation is entirely distinct from that north of the Darling, it is said to be very doubtful if the same results will follow deep boring.

I have visited a property on Oxly street, Queensland, where water strongly impregnated with salt was used for irrigating the soil for growing lucern. The owner of the land was gratified with the benefits of such irrigation, and he held the opinion that many of the salt lakes in Australia would not be looked upon as a misfortune in the future. It was, however, pointed out to him that a continuation of the use of saline water must sooner or later result in the destruction of his lucern crop.

The apparent benefit from the use of salt water was apparent from the reason that lucern to a very large degree neutralizes salt in the soil. This has often been remarked in the alfalfa (lucern) field of California, and farmers account for the fine crops of alfalfa in southern California to the alkaline soil there. It is possible that on the high dry banks of a river where the soil is deep and good and with abundant natural drainage, that saline water might be pumped on lucern fields for a number of seasons without materially injuring the soil. Of course natural conditions would have to be taken into consideration, as for instance, in the case of the land to which I have lately referred, where the subsoil is thoroughly washed over by the heavy tropical rains.

Mr. H. C. Russel, Government astronomer, who has, since his arrival in the colony in 1870, devoted great attention to water supply, is very decided in the opinion that there is an abundant supply of underground water in the western districts of New South Wales. Many theories are advanced as to its origin. Some attribute it to a flow of water from the lofty mountains of New Guinea. When Mr. Russell pointed out, about ten years ago, the remarkable relations existing between rain-fall and the rivers of the west, he was told that his statements could not be true. No rain that fell would wet the ground 18 inches deep, much less afford water for underground supplies. With equal confidence it was asserted that the water which did penetrate into the ground was all dried out of it by evaporation, and further that the greater part of the Darling River basin was so flat that the water would not flow, and the rain, therefore, did not and could not find its way into the river. Mr. Russsell determined to wait the results of several years of patient investigation before speaking again. With regard to the first objection he has affirmed that in heavy rains water reached the Darling from the flat countries.

Evidence as to this fact was found in the rain-storm during 1885. In regard to the water from the mountains of New Guinea he said that, even admitting the theory, the area was insufficient. He did not think the water which flows into the Darling passed into the ground, although

it was in evidence before the royal commission that parts of the Darling River basin were exceeding porous and allowed the water to sink down freely.

It is the opinion that irrigation in most parts of this colony from tanks is practically impossible, as water conserved in excavated reservoirs would cost about 6 shillings ($1.46) per 1,000 gallons, a price practically prohibitive. The future of irrigation seems to be largely dependent on the storage of some portion of the flood-waters now running to waste, and this can not be effected by expensive works confining such storage waters to the river channels, which, under the most favorable conditions, would only provide for watering a narrow belt on either side of the river channels, but must be effected by diverting and storing the water in the basins or lakes that nature has formed and into artificial basins or reservoirs constructed, as in America and other countries, among the hills, from whence it could be distributed by gravitation.

CHARACTER OF WORKS USED.

As already stated, irrigation in New South Wales has hitherto been confined to lands bordering on or adjacent to one or other of the rivers, and no works have been undertaken to increase or regulate the supply. Where the country is suitable the distribution is effected by channels or ditches laid out so as to conform to the features of the ground, and of sizes proportionate to the duty they may be required to perform. Pumping water for irrigation effected by Tangee centrifugal pumps, sometimes by windmills. The water is pumped up into storage tanks of iron or brick and then run off by gravity on to the land to be irrigated in pipes.

This method is, I think, peculiar to Australia. I have never observed it in California, or indeed in any other part of the United States with which I am acquainted. In portions of the country where the rainfall is tropical, and the soil becomes so dry that every drop of water is precious, tanks and pumps appear to work well, as there is no waste from soakage, evaporation, or capillary attraction.

The expense attendant on the above method renders its adoption on a large scale too costly. Orchards and the paddocks around many homesteads are, however, irrigated in this manner.

On the Torrens River, in South Australia, one of the farmers uses a pump with a four horse-power engine and the water is pumped to a height of 35 feet into a square brick tank, 10 feet long, 5 feet wide, and 2½ feet deep. More than half the tank is below the surface of the ground. The water when needed is distributed through 2-inch pipes sunk under ground and laid in different directions. At intervals of from 40 to 50 feet, stand-pipes communicate with the surface, and, being furnished with stop-cocks, the water is turned on or off at pleasure. From the stand-pipes canvas hose can be adjusted and laid on to the particular spots where the water is required. To facilitate the operation shallow trenches are scooped out near the trees requiring to be watered, and the water is led from one depression to another when the lengths of hose are insufficient.

At Emu Plains an extensive orangery is supplied with water in a somewhat similar manner, but here the water is received out of a well about 30 feet deep. The Tangye pump is placed 20 feet above the water and forces it into a number of 400-gallon iron tanks arranged on trestle-work; 1,000 gallons of water are drawn from this well per hour. On the

Nepeau River a farmer has an irrigation plant which is worked by a six horse-power Tangye engine, and the lift of water is 23 feet; from thence it is forced a distance of 850 feet to the storage tanks. The cost of the engine was £110 ($535), and the piping £50 ($243). The water flows from the tanks by gravity; open furrows are used. In the Riverine district, about Deniliquin, 481 miles southwest of Sydney, where the summer winds are very hot, fruit trees are kept in full bearing by mulching, *i. e.*, spreading litter, whether leaves or other matter, around the butts of the trees. Trenches 4 or 5 inches deep are opened in the soil about 5 or 6 feet from the trees; water is let into the trenches when required. It is said to pay to adopt these means even when the water has to be carted a considerable distance. The average rain-fall in this district is only about 16 inches per annum, but nevertheless fruit is very profitably grown.

The success attending artesian well-boring in various parts of Australia led to an investigation of the subject by Mr. W. Anderson, geological surveyor, of New South Wales, and I learn from his report that the Lower Cretaceous formation in which artesian water is known to occur extends over a vast area in the eastern half of the Australian continent, occupying the greater part of the interior of Queensland, a large portion of central and south Australia, and the northwestern plains of New South Wales. The southern extension of the Cretacis-Tertiary formation occupies a considerable area to the north of the River Darling in the neighborhood of Bourke. Mr. Anderson says it is astonishing that while this formation has been known for many years, pastoralists on the northern plains did not until recently realize the fact that they have beneath them an invaluable supply of water. He does not recommend boring for water where Silurian slates occur, for the reason that all the Silurian rocks of the district have a general strike of E. 20° N., and stand nearly vertically, therefore they can not possibly hold water in any abundance, and where Silurian formations occur there is always a thinning of the Cretaceous beds.

The principles which govern the location of water in the deep-seated beds of the formation, such as the Cretaceous and its subsequent rising to the surface as artesian water when tapped, are gravitation and the fact that a confined and continuous flow of water must rise to the level of its hydraulic grade. Mr. Anderson directs attention to five positions in which water may be found in the flat western country:

(1) In the Cretaceous formation itself;

(2) Between the Cretaceous formation and the Silurian bed-rock on which it rests;

(3) In the silted up Pleistocene river channels;

(4) In the immediate neighborhood of the present water-courses; and

(5) In the superficial portions of granite, as at Byrock.

The water in most of the wells that have recently been sunk is in quantity sufficient to indicate a permanent flow.

Such water is used for irrigation by gravity at very little cost.

SYSTEM OF WATER DISTRIBUTION, WHETHER GOVERNED BY LAWS OR CUSTOMS.

All irrigation works in New South Wales have hitherto been carried out out by private enterprise. Each owner appears to be a law unto himself, and so long as he does not interfere with his neighbors' water rights is subject to neither rules, regulations, nor customs. In Victoria there is an irrigation act, and the necessity for passing a similar act in this colony is urged very strongly by both press and people.

It would be very difficult to form anything like a just estimate of the quantity of water used per acre in New South Wales. The consumption of water on the River Murray, which is the boundary between the colonies of New South Wales and Victoria, for farms in Victorian territory, and which cover a larger area, is, however, very considerable.

The peculiar river system of Australia has been explained in my published Report on Irrigation, and I will not now refer to it further than to say that the Murray is the most important river in Australia, and together with its tributaries drains an area of 27,000 square miles.

The Murray is navigable for boats of light draught for a distance of 1,700 miles from its mouth. In making its way towards the ocean it passes through a considerable portion of the colonies of Victoria and South Australia. New South Wales, although by her constitution, received from Great Britain, entitled to the control of the river, has taken no effective steps to utilize its waters for the purposes of irrigation.

Both the other colonies have, practically, taken possession of the watercourse, and I learn from a report just submitted to the New South Wales parliament, by Mr. J. E. F. Coyle, civil engineer, who has investigated the condition of the Murray, its navigation and use of water for irrigation, that out of one hundred and forty-three steamers engaged in the river trade, sixty-seven are owned in Victoria, fifty-five in South Australia, and only twenty-one in New South Wales. Mr. Coyle states that the other two colonies have ignored New South Wales, not only in regard to the trade on the river, but as to the use of the water for various irrigation schemes.

A number of wharves have been erected on the Victorian side by the Government there, together with sheds, plants of machinery, and other works which Mr. Coyle considers inconsistent with the ownership of the Murray by the colony of New South Wales. Since 1886, when the Victorian act authorizing the construction of works on the Murray for irrigation was passed into law, as many as sixty-three different water interests have come into force for irrigation purposes, and the quantity of water being now drawn from the river is exciting alarm among the people of New South Wales. These Victorians consume in summer 102,000 gallons, and in winter 61,800 gallons per twenty-four hours; also 46,579 cubic feet in summer and 161,618 cubic feet per minute in winter.

The Victorian Government has employed steamers in clearing the river from snags and other impediments.

The Government of New South Wales, of course, does not object to that, and it is scarcely probable that she would claim, in spite of her constitutional rights, a supreme control over all the advantages to be derived from the river, but she will undoubtedly object very seriously to any other colony doing so. The Victorians, however, contend that they are simply using the water that otherwise would be wasted, and besides that they have never been granted the right to use it for an indefinite period, for their Government in licensing irrigation works have expressly provided that water can be taken from the Murray only so far as it is in the power of the Government to permit.

Sir Henry Parkes, premier of New South Wales, in a powerful speech delivered in Parliament lately, pointed out what he deemed an aggression on the part of the Victorian Government upon the constitutional rights of New South Wales and very earnestly urged further legislation upon the subject.

The trouble is the question of right to control the waters of the Murray

can not be settled by one colony alone, and will probably have to be dealt with at an intercolonial conference at which each of the colonies interested can take part, and an agreement reached by which the benefits of their principal water-way tribute may be shared alike.

CHARACTER OF CLIMATE, RAIN-FALL, ETC.

The colony of New South Wales extends through eleven degrees of latitude, it being entered on the parallels 28° 10′ and 37° 38′ south latitude, and between the meridians 141° and 153° 38′ east longitude. The area embraced within these limits contains 310,938 square miles, or 199,000,000 acres.

The climate extending through so many degrees of latitute, very naturally permits almost any variety, from hot to cold.

The northern part of the colony resembles that of the south of Italy, Spain, and Greece, while the southern portion is not wholly unlike that of northern California.

At Kiandra frost and snow prevail for a considerable part of the year; but on the plains of the interior the thermometer rises to 130° above zero, and sometimes there is no rain for eight months in the year.

The average annual rain-fall, according to a recent return supplied by the Government astronomer, Mr. H. C. Russell, was 23.68 inches for a period of fifteen years, from 1874 to 1888, the lowest average being for 1888, when it was 13.40 inches, and the highest in 1887, when it reached 34.39 inches. Mr. Russell has prepared the following table to show the average rain-fall in New South Wales for each year from 1874 to 1888:

Year.	Inches.	Year.	Inches.
1874	33.46	1883	17.96
1875	29.38	1884	15.86
1876	27.66	1885	19.48
1877	20.48	1886	26.04
1878	25.05	1887	34.99
1879	30.75	1888	13.40
1880	19.93		
1881	20.73	Mean, fifteen years	23.68
1882	20.11		

Mr. Russell states that the drought in 1888 was the most severe ever experienced, but during November and December rain fell and broke up the terribly dry weather.

During December, 3 inches of rain fell at upwards of two hundred recording stations, chiefly along the coast line, while the great western plains, which needed the rain most, remained to the end of the year in a state of drought. Not once during the year did rain enough fall on these plains to make water run on the surface of the ground.

On the Marano River the four months of winter passed with only .03 inch of rain. Even the native trees died for want of water in some places. In Sydney the average rain-fall for a month is about 4 inches; but over large areas in the west the rain-fall for the whole of 1888 was under that amount.

At South, on the Darling, it was 2.47 inches; at Menindie 2.82 inches. Mr. Russell remarks, that living in a moist climate near the sea, it is difficult to realize what such a record means in a dry, windy, hot place.

The wonder is that plant or animal can live through it. Then, taking the mean of fifty places, the rain-fall for the whole colony was 43 per

cent. below the average, and it is noteworthy that the rain-fall of 1887 exceeded the average by 42.7 per cent.; so the wettest and driest years on record are side by side showing a difference in rain-fall amounting to 85.7 per cent of the average.

When forwarding some valuable publications, Mr. Russell remarks in his letter to me of 28th September that, knowing what important questions could only be answered by statistics about rain, rivers, and evaporation, he began to collect them and to educate the people to keep rain records. In 1870 he found five meteorological stations at work. Now they number nearly one thousand. Records of the heights of the western rivers were begun in 1862 by Government officers, but they were not kept up In the annual rain reports are to be found every known rain-fall record for this colony. Mr. Russell has the control of the rain-fall records, and he states they are fairly complete for a young country, but the work of carefully gauging the output of the rivers has not yet been commenced by the Government. The records which he gives of the water at each place, the water velocities, are not measured, because competent officers for that work have not yet been stationed on the rivers. The velocities he has used were determined years since, and are assumed to hold good for the same height of flood for each year.

Since 1887, however, officers from Victoria have been systematically measuring the discharge of the river Murray, and have so far confirmed the results which Mr. Russell had obtained in the way indicated.

ANTIQUITY OF IRRIGATION SYSTEMS.

The remarks I have made in this report show that the various modes of irrigation practiced in New South Wales are wholly of recent date. The maps and publications which the Department of State direct me to obtain for the select committee of the Senate on the subject of irrigation are enumerated in the following list:

List of printed documents and maps relating to irrigation and reclamation of arid lands; sources of water supply; systems of water distribution; character of climate, and so far as relate to the colony of New South Wales.

1. Royal commission. Conservancy of water. First report of the commissioners. 1885.
2. Maps, diagrams, and plans referred to in the above report. 1855.
3. Royal commission. Conservation of water. Second report of the commissioners. 1885–'86. (Maps and plans are attached.)
4. Royal commission. Conservation of water. Third and final report of the commissioners. 1887.
5. Maps, plans, and diagrams to accompany the above report. 1887.
6. Royal commission. Conservation of water. First report of the commissioners. Abridged edition. 1886.
7. Royal commission. Conservation of water. Third and final report of the commissioners. Abridged edition. 1887.
8. New South Wales, her commerce and resources. By Consul Griffin. Report on irrigation. Pages 13 to 21. 1888.
9. Climate of New South Wales, descriptive, historical, and tabular. By H. C. Russell, B. A., F. R., A. S. 1887.
10. New South Wales. Physical geography and climate. By H. C. Russell. 1884.
11. The river Darling. The water which should pass through it. By H. C. Russell. 1879.
12. Some facts bearing upon irrigation. By H. C. Russell. 1883.
13. Notes upon the history of floods in the river Darling. By H. C. Russell. 1886.
14. Notes upon floods in Lake George. By H. C. Russell. 1886.
15. The source of the underground water in the western districts. By H. C. Russell. 1889.
16. Notes on the experience of other countries in the administration of their water supply. By H. G. McKinney, C. E. 1887.

Rivers of New South Wales. By H. G. McKinney, C. E. 1888.

18. Water supply in the interior of New South Wales. By W. E. Abbott. 1884.
19. Forest destruction in New South Wales and its effects on the flow water in water-courses and on the rain-fall. By W. E. Abbott. 1888.
20. On wells in Liverpool plains. By T. K. Abbott, P. M. 1880.
21. Metropolitan water supply. By Mr. James Manning. 1875.
22. Comparison between the Prospect and Kruny Hill schemes, proposing a high-pressure water supply for Sydney. By F. B. Gibbs, C. E. 1880.
23. Importance of a comprehensive scheme of water storage and canalyzation for the future welfare of New South Wales. 1881.
24. Tanks and wells of New South Wales. Water supply and irrigation. By A. P. Wood. 1883.
25. Results of rain, river, and evaporation observations made in New South Wales, 1879 to 1888. By H. C. Russel, F. R. S., Government astronomer of New South Wales. 1879 to 1888. (Ten parts).

The documents above enumerated are forwarded to the Department of State in separate cover.

Additional information, publications, maps, and plans have been promised me in time for transmission by next mail. I have reason to believe that the whole will form the most complete collection of literature on irrigation and water conservancy ever brought together relating to New South Wales.

LETTER FROM MR. JAMES WILSON TO CONSUL GRIFFIN ON IRRIGATION IN NEW SOUTH WALES.

COMMERCIAL, PASTORAL, AND AGRICULTURAL
ASSOCIATION OF NEW SOUTH WALES,
40 *Hunter Street, Sydney, August* 28, 1889.

SIR: I have received from you questions on the subject of irrigation and the reclamation thereby of arid lands, with information that a special committee has been created by the Senate of the United States to investigate the questions involved.

The collation and systematic organization of reports on this subject from all parts of the world which your consular system affords can not fail to be of the greatest public utility, not only to the United States but to every arid corner of the universe, and it is to be hoped the committee will produce a report on a comprehensive scale which, when published, will prove of immense benefit to generations yet unborn.

For some time the Commercial, Pastoral and Agricultural Association of New South Wales has been engaged in noting the steps taken in this colony to deal with the arid lands in her vast interior and in collecting documents showing the great aid afforded by the Royal Society of New South Wales and kindred scientific associations for dealing with the local question, and in contrast with other countries, from more or less unofficial sources. I shall have much pleasure in placing these records at your disposal.

To my mind the question to Australia of water conservation, distribution, the development of underground reservoirs proved to exist, the economical adaptation of such, and rain-fall observations as will minimise waste from the effects of periods of drought, by regulating supply, is as necessary as a mainspring to a watch. Upon the satisfactory solution of water difficulties depends the future development of this vast island continent, whose very existence a century ago was comparatively unknown. Of this continent New South Wales embraces a territory of 195,882,012 acres, and her present record of population is only a little over one million. To the United States our population and occupancy of territory when compared must form an insoluble problem; but the key is to be found in the pastoral stage of development in civilization during the nineteenth century, as practiced in Australia, and when we compare the numbers of the population actually outside our towns and cities the position will appear more explicable why we can not in the present stage point to existing irrigation and water conservation works and irrigable and non-irrigable areas and their results. The works in existence at present are only the outcome of private individual enterprise within freehold limits and bear no proportion whatever to the exigencies or necessities of the country at large, its rain-fall or river systems.

The mode of land tenure, the centralizing departmental form of government, and political inability to deal with so extensive a public estate upon a broad and national basis, are the true causes of neglect of and inertia towards our progress in this direction. It is from no want of consideration or inability on the part of our best men to grasp the importance of the situation, but from the general *laissez-faire* of our political economy which provides that all public works in the colony are conducted and

controlled by government departments centered in the city of Sydney, not in touch with what might be termed local or district wants, and resenting interference with their prerogative unless under political pressure—a system which ascribes drought and disaster to Providence and fails to use means nature has provided for amelioration.

A more valuable compendium of information from many sources on irrigation in New South Wales than that presented in your consular report to the Department of State, Washington, republished by the New South Wales Government in 1888, does not exist, nor one more truthfully and fully describing this country; and I would respectfully suggest that that report be laid before the committee of the Senate. You have fairly pointed out the difficulty of riparian rights as they exist at present and the incidence of common law as prohibitive to deal with water conservation on a comprehensive scale, and you have cited the opinions of the water conservancy commission, appointed in 1884; it only now remains to supplement this by reference to their report in 1887, since published.

There have been no water-trusts created and no law changing riparian rights in this colony. The first bill in New South Wales to provide a water-trust, a municipality bill for the irrigation of a town common at Wentworth of 21,000 acres, on the New South Wales side of the river Murray, is now before parliament. Successive governments have for years past promised a scheme of local or district government which will embrace powers for dealing with water and irrigation by local trusts. Hitherto in this colony the public works for water conservation have been confined to constructing watering stations on the traveling stock routes in arid districts, wells, tanks, and dams. The government first recognized the necessity for such in 1869, and in 1888 it would appear from a statement relating to watering places, one hundred and forty-four in number, that an expenditure of over £270,000 ($1,313,955) had been made in construction and appliances, their maintenance costing over £25,000 ($121,663) per annum. These works have no doubt exercised a large and beneficial influence upon our pastoral progress.

I would suggest that you obtain from the government printer, Sydney, such official documents bearing on the subject as have been printed from time to time.

It only now remains to state that the government has conducted preliminary steps to carry out a scheme of irrigation and water-supply by canals, submitted to the water commission by H. G. McKinney, civil engineer; surveys are completed and the engineers are now taking levels for canals near Albury, on the Murray River. The main Albury canal will be 176 miles in length Jerilderie branch canal 33 miles, and the Tuppel branch 31 miles, a total of 240 miles. The estimated cost of this undertaking is £1,500,000 ($7,299,750), and the area to be irrigated 570,000 acres.

To water conservation and irrigation as presented in other countries, and especially in India, all our New South Wales and Victorian schemes must appear insignificant; but we are only a young country and a small community anxious to profit by the experience of others, and will gladly benefit by the results of the inquiry being made by the special committee of the United States Senate, embracing as it will consular reports from all countries.

I shall have pleasure in forwarding your inquiries in any way in my power.

I remain, with much personal esteem, yours faithfully,

JAMES WILSON.

G. W. GRIFFIN,
U. S. Consul, Sydney.

SOUTH AFRICA.

REPORT OF GEORGE F. HOLLIS, U. S. CONSUL, CAPETOWN, ON IRRIGATION IN SOUTH AFRICA.

South Africa has been described by some one as a country in which the rivers have no water. This is only too true during a portion of the year, while during the rainy season the rivers have a torrential character and the traveler must perforce halt at the river banks and wait for the rain to run by.

Until recently irrigation has been a matter of private enterprise and the works have been of the simplest and cheapest character. Wherever springs have been found it has been the custom to strengthen them by the building of a primitive dam above the spring's source, and the water so consumed is then conducted by a system of furrows over the area to

be benefited. Where the water of rivers could be utilized the same system of furrows is followed and narrow strips of land on either bank of the stream are thus brought under a higher system of cultivation and large crops are the result of such a system.

Irrigation in this primitive way may be said to be the rule in the South African Republic, the Orange Free State, and in a large portion of the Cape Colony. In 1877 the Government passed an act for the promotion of irrigation, the principal provisions of which are as follows: Any three or more owners of land within any area in which it is deemed expedient to store water by artificial means for the purpose of irrigation may petition the government to proclaim such area an irrigation district, provided such petitioners shall be the owners of not less than one-tenth of the land in such district to be proclaimed. The governor may then dispatch an engineer or other competent person to the locality, where a public meeting of land owners is called, after due notice, and a report is sent to the governor as to the propriety of constituting such irrigation district. Should such report be favorable and receive the assent of two-thirds of the owners of land situated within its area, the governor may proclaim such district an irrigation district. The performance of all acts, etc., relating to irrigation and the storage of water in such proclaimed district shall be vested in a board having corporate powers, to be chosen from the land owners of such district. Every owner of land is entitled to vote at an election for members of such board, and shall have one vote for each $500 valuation of land.

The charge and conservation of every natural river, stream, creek, and water-course, and of every dam, pond, and embankment within the limits of an irrigation district which is by its nature common to two or more of the owners of land within such district, and the absolute control and regulation so far as the same can be effected by artificial means of the supply of water throughout the course of any such river, stream, etc., within such limits, shall be vested in the irrigation board of such district. Such board shall have power to cleanse, repair, and maintain in a due state of efficiency any stream, river, etc., as above; to deepen or otherwise improve such water-course, and to erect dams, reservoirs, etc.; in fact, to maintain, improve, and construct any works that shall be necessary for the proper storage and conservation of water for irrigation purposes.

Provision is made for full compensation for any injury sustained by any person by reason of the exercise of the powers of the board. The board may also enter and take possession of any land, covered or uncovered by water, as may be necessary to carry out the purposes of this act. The board may levy rates at so much per acre in all land within the area which is irrigated or capable of being irrigated, provided that no land shall be taxed that is otherwise irrigated or improved by means contemplated by the act.

Power is given the board to borrow money either by public tender or from funds provided by Parliament, in which latter case the governor may loan to the extent of one-half of the value of the lands; such loan to be a first charge on the same, and he may appoint officers to inspect such lands and works.

IRRIGATION BY PRIVATE OWNERS.

Any owner of land, not within the limits of any irrigation district, proposing to improve the same by the storage or conservation of water and desiring a loan from the Government for such purpose, may make

application for such purpose, giving bonds for the payment of the cost of investigation, and the governor may then cause lands, plans, estimates, and specifications of proposed works to be inspected and reported on. Provision is made for the loaning of money by the Government under due restrictions, which becomes a first and preferment charge upon the land at the rate of 8 per cent. for the term of twenty-four years.

Any mortgagee having claim on land must join with the holder of the title thereof in an instrument to be filed with the registrar of deeds. Provision is made for arbitration, the making of by-laws and regulations and penalities for the fraudulent taking or polluting of the water, or for obstructing or impeding the flow of water within the area proclaimed.

Two years later an act was passed by which provision was made for the loan of money by the colonial government to municipalities desirous of such assistance in carrying out works of irrigation, the terms of which are similar to the act of 1877, and provide that the interest in such loan shall be provided from the rates levied by the towns availing themselves of the provision of the act. The act of 1877 was amended in 1880, providing for the advance by the Government of the loan made by advances of one-fifth of the amount, and making provisions for repayment of the loan according to the following schedule:

SCHEDULE A.

If the owner shall desire to repay the sum advanced in one year, the rent charge for one year shall be per centum, £106; if he shall desire to repay it in two years the annual rent charge shall be, per centum, £54 11*s.*; if in three years, £37 8*s.* 6*d.*; if in four years, £28 17*s.* 6*d.*; if in five years, £23 15*s.*; if in six years, £20 7*s.*; if in seven years, £17 19*s.*; if in eight years, £16 2*s.*, 6*d.*; if in nine years, £14 14*s.*, 6*d.*; if in ten years, £13 12*s.*; if in eleven years, £12.14*s.*; if in twelve years, £11 19*s.*; if in thirteen years, £11 6*s.*; if in fourteen years, £10 15*s.* 6*d.*; if in fifteen years, £10 6*s.*; if in sixteen years, £9 18*s.*; if in seventeen years, £9 11*s.*; if in eighteen years, £9 5*s.*; if in nineteen years, £8 19*s.* 6*d.*; if in twenty years, £8 14*s.* 6*d.*; if in twenty-one years, £8 10*s.* 6*d.*; if in twenty-two years, £8 6*s.* 6*d.*; if in twenty-three years, £8 3*s.*

SCHEDULE B.

The present value of every £1 per annum rent charge shall be:

For one year, £0 18*s.* 11*d.*; for two years, £1 16*s.* 9*d.*; for three years, £2 13*s.* 6*d.*; for four years, £3 9*s.* 4*d.*; for five years, £4 4*s.* 3*d.*; for six years, £4 18*s.* 4*d.*; for seven years, £5 11*s.* 8*d.*; for eight years, £6 4*s.* 3*d.*; for nine years, £6 16*s.* 1*d.*; for ten years, £7 7*s.* 3*d.*; for eleven years, £7 17*s.* 9*d.*; for twelve years, £8 7*s.* 9*d.*; for thirteen years, £8 17*s.* 1*d.*; for fourteen years, £9 5*s.* 11*d.*; for fifteen years, £9 14*s.* 3*d.*; for sixteen years, £10 2*s.* 2*d.*; for seventeen years, £10 9*s.* 7*d.*; for eighteen years, £10 16*s.* 7*d.*; for nineteen years, £11 3*s.* 2*d.*; for twenty years, £11 9*s.* 5*d.*; for twenty-one years, £11 15*s.* 4*d.*; for twenty-two years, £12 0*s.* 10*d.*; for twenty-three years, £12 6*s.* 1*d.*

As early as December, 1881, no less than sixty applications had been made by the districts desiring to avail themselves of the terms offered by the Government. Owing to the peculiar character of the topographical features of the country and the fact that most of the rivers of South Africa are dry in the summer and flooded during the rainy season, a vast deal of scientific labor must be expended in order to determine the sites most advantageously situated for the construction of storage basins and other irrigation works. Topographical and geological surveys are being made under the direction of the Government.

It will probably be found necessary to make the formation of water boards compulsory, so that those land-owners situated above areas

already proclaimed will be amenable to Government supervision in the conservation of their water courses. Wherever irrigation has been properly tried in the colony it has met with unqualified success, assuring large crops to husbandman and guarantying the stock-raiser against loss by drought.

From the lamentable reports now coming in from the up-country of the great loss of sheep by reason of the almost total lack of rain-fall this winter, I should judge a great impetus will be given to this question. Many farmers have reported a loss of from 10 to 50 per cent. of their stock, which would not have occurred had the districts been secured against drought by storage basins. Some idea of the enhanced value of irrigated land may be seen in the report made by one owner, who stated that his increased rentals would repay the loan for four years.

The most complete storage work completed in this colony, and the most important, is that of Van Wycks Valley, full reports of which with accompanying maps, Nos. 1, 2, 3, and 4, I send by book-post in to-day's mail. The rain-fall in this section is very irregular, the average for eleven years having been 10 inches, and in some years falling to 3 and 4 inches. The reservoir has depended on the catchment area of, say 240 square miles. This has been found to be insufficient for a full supply, and a furrow is now nearly completed through which the water of a neighboring river will be brought in, by which it is estimated that the water-covered area will be increased to 19 square miles with a depth of 27 feet.

The land under irrigation is held by the Government and is leased at a minimum price of 10 shillings per acre. The bailiff in charge has the sole control of the flow of water and uses his discretion in its supply, some land within the area requiring more water than other portions. Owing to many causes, the chief of which was ignorance of the character of the land—fostered by the report of interested persons who declared that the water would prove to be too salt for agricultural purposes, and who desired the work should fail and be abandoned, giving them a chance to acquire it—the poorest tenants, mostly assisted by the Government supplying seeds, were alone secured. Their success has, however, been so marvelous that the lands will soon be eagerly sought after. It is estimated that last year 1,300 acres were irrigated at an expenditure of an inch of water per month from the surface. The rain-fall over the whole colony is so irregular that I have taken the subdivisions of the colony for the purpose of comparison and have summarized the reports from an average of six stations in each district. The rain-fall for these districts for the year 1888 was as follows, in inches:

	Inches.
No. 1. Cape Peninsula	53.84
No. 2. Southwest	32.95
No. 3. West coast	15.18
No. 4. South coast	33.60
No. 5. Southern Karroo	17.59
No. 6. West Central Karroo	14.12
No. 7. East Central Karroo	16.15
No. 8. Northern Karroo	11.43
No. 9. Northern border	8.84
No. 10. Southeast	28.17
No. 11. Northeast	20.39
No. 12. Tianskei	25.00

The topographical features of South Africa are so peculiar that the system answering for one district is not applicable to others, while the rain-fall varies greatly as one leaves the coast and ascends to the vari-

ous table-lands. In general, it may be said that, the land being almost entirely denuded of trees and bush, the rain is not drank up by the soil but runs rapidly over the surface, seeking its natural outlet to the sea, while the evaporation is very great, estimated at 6 feet at Van Wycks Valley, necessitating deep storage basins.

Streams which are alive the whole year are very few.

Boring for water has not been attempted on a large scale, but the experiments made in certain sections have given very encouraging results.

SOUTH ATLANTIC ISLANDS.

REPORT FROM THOMAS C. JONES, UNITED STATES CONSUL, FUNCHAL, ON IRRIGATION IN MADEIRA.

In answer to your circular and inquiries in regard to the system of irrigation now in practice on this island, I beg to submit the following report:

I can not answer your questions in as full a manner as I should like owing to the meagerness of statistics.

The public works here are of the most primitive kind. The same implements that tilled the soil and constructed the water-ways three hundred years ago till the soil and construct the water-ways of to-day. Stone is plentiful and labor is cheap; the island is furrowed with water-ways, but the new is no improvement on the old.

(1.) The area of Madeira is about 240 square miles. About one-half of the island is in cultivation. The whole of the sea-board is more or less cultivated by irrigation.

Where water is plentiful such crops as sweet potatoes, beans, cabbages, etc., are grown as high as 3,000 feet elevation above the sea; but maize is seldom grown above 800 or 1,000 feet, owing to the short summer season on the hills.

The area which is under cultivation by irrigation with sugar-cane, potatoes, onions, maize, etc., and almost at all seasons, and where, therefore, the population is concentrated, varies between 500 and 1,500 feet above sea-level, and may be estimated at a little more than one-third of the whole area of the island.

It is difficult to estimate the quantity of the crops grown, as the exports are pretty well limited to sugar, wine, onions, potatoes, and bananas. Sweet potatoes, which is probably the largest crop grown, beans, cabbages, are consumed in the home.

Almost all the cereals and food plants are grown in Madeira.

The wheat is of the bearded kind, with a hard, semi-transparent grain, and commands a better price than the imported. A large part of the vegetable subsistence is derived from the pumpkin tribe.

The banana is one of the best paying crops. It is confined below the 500-feet line. Oranges grow at an elevation of 1,500 feet.

(2) The water supply is derived from perennial springs and from the many gorges which carry off the water from the hills to the sea during the rainy season. After May these gorge streams are quite dry long before they reach the sea, their water having been drawn by the different levadas.

The north side of the island, being more precipitous and well-wooded, supplies its different levadas as well as several of those on the south side.

There are no reservoirs or catchment basins. They would be expensive to make owing to the precipitous nature of the hills, and it is doubtful whether the broken and rocky hillsides would hold the water unless the whole bottom were concreted.

(3) The character of the works used for distribution of irrigation water is levadas or open culverts. These are constructed of masonry or cut in solid rock at high levels. They pass through tunnels, over bridges, and along the sides of precipitous mountains, carrying the water to the cultivated lands below.

Some of these levadas are a few miles in length while others are 60 and 70 miles long.

(4) The system of water distribution is governed by custom and the flow is rated by the hour.

Some levadas deliver their whole contents during an hour or more as the proprietors of the water may be entitled to it. Others deliver say one-quarter of their contents at a time. The irrigator only requires the quantity of water at a time which will run along a furrow without washing the soil away.

The Sta. Lugia levada, for instance, contains 4,245 horns of water, to which there are proprietary rights acquired by purchase from the original makers or by inheritance. It now takes fifty days for each proprietor, of one hour to have his turn again; but he receives it instead by the quarter, every twelve and one-half days.

Besides the proprietary right there is in all levadas a right of water which belongs to the levada, and the committee of management for the year sells this water in January for the benefit of the levada, for repairs, etc., the water being plentiful at that season.

During the recent sugar-cane disease the price of an hour of water fell 50 per cent. in the Sta. Lugia Parish, viz, from $6 to $3.

Each piece of ground within the district of a given levad is entitled to its hours of use of the stream. For eight or nine months of the year the water is turned on to the proprietors as they may desire, but when the dry season sets in the committee puts it a "giro" or space of time occupied in making the tour of the whole district, which giro varies from 15 to 60 days, according to the extent of the district.

The "Levadeiro" or distributor of water is a salaried official, paid by the committee. He also collects a small fee of about 3 cents per hour per annum of the proprietary rights, and a higher fee on rented water. These fees are fixed annually by the committee.

When extensions or repairs of any magnitude are undertaken the money is borrowed, usually from the proprietors, and paid back in water or by rates levied over preceding years.

The foregoing applies to the old levadas, which were constructed by the proprietors.

No two levadas are alike in their volumes of water, in their velocity, or in their rates. In the neighborhood of Funchal the price of an hours rain in the season is from $5 to $8, while on the north side of the island it will never exceed $1 per hour.

The Government has, during the last fifty years, constructed levadas, which collected the waters in almost inaccessible gorges on the north side of the island, and conduct it to the warm south side. These waters are distributed to the cultivators of the soil at a nominal cost.

But when the Government levada is completed, and leaves the hands of the department of public works for those of the local, it gradually falls into ruin for want of attention.

No repairs can be made without estimates, and these have to be submitted to Lisbon for approval, and when approved, the time is generally so long that the original estimates are insufficient.

As water is the most valuable property in Madeira there is more quarreling about it than about anything else in the island. It is a fruitful source between the well-to-do and the poorer class. More people go to prison for stealing and tampering with water than for anything else.

One of the principal difficulties attending the management of the levadas was the want of a legal standing as corporate bodies of their committees. A quarrel between two levadas, draining their supply from the same valley, occasioned a lawsuit which has lasted now more than forty years. Within the last few years a law has been passed enabling the committees to incorporate themselves, with power to acquire property, and otherwise protect and improve their levadas.

They can purchase the land containing their springs, protect the forest and the trees along their lines. Every farmer of thrift has on his land tanks to store his water, and from these tanks little levadas distribute it when and wherever he wants it.

Water rights are held under title deeds, which specify the intervals at which the supply shall be given and the length of time it shall continue. Water is always of ready sale. If a crop fails from any cause the water for that land is sold to a more fortunate neighbor; though sometimes at a very reduced rate, as was the case in the time of the sugar-cane disease.

Under any system, it is hard for the poor. Their supply is scant, and they must receive it when their time comes, seasonable or unseasonable, day or night, and without tanks they can not care for or properly distribute it.

(5) The irrigated region is the coast belt, which during the summer season will produce crops that will ripen before the early autumn sets in. The nearer the seashore, with its consequent semi-tropical heat, the more valuable becomes irrigation.

The annual rain-fall in Funchal is about 28 inches; but the hills which supply the springs are almost always covered with clouds and wet mist, the water contents of which can not be estimated.

The soil varies in quality. That of the coast belt is calcareous tufa, with an admixture of vegetable matter, and is very rich. Wheat and barley are grown on the same land from generation to generation with hardly any application of manure.

The soil best adopted to the vine is a decomposed red tufa, especially where there is an admixture of stone with it. The hill regions have a stiff, clayey soil.

(6) There are levadas here probably 300 years old, but several of these have had their courses changed during political troubles and from other causes.

The levada, for instance, which now irrigates St. Vincente on the north side of the island, was constructed by the inhabitants of the Brava Valley on the south side, and was lost to them during the interegnum between the Spanish and Portuguese occupation. The Government is now constructing a levada, which will collect its waters in the hitherto quite inaccessible Inferno Gorge for irrigating the St. Vincente Valley, when it will restore to the Brava Valley the levada which originally belonged to it.

The source of this new levada is at the height of 4,700 feet above the sea, and after entering the valley it is intended to throw the water down a series of cascades with a fall of more than 300 feet.

A constant flow of a pint of water is sufficient to irrigate 5 acres of ground; that is, the water must flow into a reservoir and be used from that as required.

I have had translated the "Regulation for the Government of the Government Levadas of the Island" and have had it attached to this report. There are no maps or drawings of these works obtainable.

The engineers, contractors, and others who build our Government levadas come from Lisbon, and the plans, estimates, etc., are kept there in the office of public works. There are no publications that I can find.

Mr. John B. Blandy, of this city, is the largest land and water proprietor on the island. He has had more to do with the construction and working of these water ways, and is probably more of an expert than any person on the island. I am indebted to him for this report. He will take pleasure in giving the Senate Committee any facts that are in his possession.

PROVISIONAL REGULATION FOR THE GOVERNMENT IN THE DISTRICT OF FUNCHAL, THEIR ADMINISTRATION AND THEIR RESPECTIVE REVENUES.

FIRST PART—THE LEVADAS.

ART. 1. The regulation of the government levadas in the district of Funchal and the superintendence of the revenues of same are under surveillance of the treasurer of the same district, according to the decree published on the 10th of November, 1849, and the regulations for the administration of the public revenue, published on the 28th of January, 1850; also a Government grant, published on the 14th of September, 1860.

ART. 2. The levadas that belong to the government in the said district are the following:

Rabacal, in the parish of Calhéta, Fajaã dos Vinhaticos, in the parish of Santa Anna, Iuncal, and Furado, that irrigate Santa Cruz and Machico.

ART. 3. The Levada Rabacal will continue to be divided into two branches, one that irrigates Calhéta and Estreito, the other that waters Prazeres and Fajaã da Ovelha.

ART. 4. The Levada Fajaã dos Vinhaticos will continue to be divided into two parts, each containing an equal quantity of water.

ART. 5. Levada Iuncal and Furado are also divided into two branches, one that irrigates the parish of Santa Cruz, the other, Porto da Cruz.

ART. 6. To superintend the said levadas there will be appointed a staff of men, to be paid by the treasury of the home government.

ART. 7. The number of men, their rank, and respective salaries for each levada will be as follows:

Levada do Rabacal.

One director, with a salary of 17 per cent. on the revenues of the levada, calculated to be	$156.67
Two levadeiros (or water men), at $24 each	48.00
Two caretakers at 24 cents daily, each	175.20
Total	379.89

Levada Fajaã dos Vinhaticos.

One director, with a salary of 8 per cent. on the revenne of the levada	$43.00
Two levadeiros, at $16 each	32.00
One caretaker, at 12 cents per day	43.80
Total	118.80

Levada Iuncal and Furado.

One director, with a salary of 8 per cent. on the revenue of levada	$44.16
Two levadeiros, at $16 each	32.00
One caretaker, at 12 cents per day	43.80
Total	119.96

ART. 8. Besides the above items, which are for salaries, there will be another item of $180 yearly to compensate any deficiency in the salaries.

ART. 9. For directors of the levadas are appointed by government under the proposal of the treasurer, and keep the appointment as long as they are worthy of it.

ART. 10. The levadeiros are appointed yearly by the delegate of the treasurer under the proposal of their respective directors.

ART. 11. The caretakers are appointed by the delegate of the treasurer under the proposal of their respective directors.

ART. 12. The duties of the director of the levada are permanent and are as follows:

I. In the proper season for irrigation he is bound to see that the waters are fairly distributed.

II. To make as far as it lays in his power all the waters enter into the levada, so that the lessee of the water may have his share or more when his turn comes to irrigate his ground.

III. To have repaired any small damage made to the levada when necessary, having it in his power to call for help should he be unable to attend immediately to the said repairs.

IV. To avoid the loss of water should he know it, and give notice, etc., of same to the administrator of any damage done to the levada. If there are damages he may appeal to the department of government works.

V. To watch that the duties of the levadeiro and caretaker are properly carried out.

The director of the levada is answerable for its good keeping and also of the small canals that bring the water from the springs.

ART. 13. The duties of the levadeiro last during the irrigation season only. They are bound to deliver to each lessee the quantity of water that he rents to irrigate his ground according to a list given him by the clerk (or tax collector).

ART. 14. The duties of the caretakers are permanent and are as follows:

I. To live close to the levada.

II. To watch in summer and winter the levadas, that they are kept in proper repair, and that the springs are drained so as to enter the levadas.

III. To keep all the traps of the levadas open when it rains.

IV. To clear all obstacles that are carried by the water that may cause overflow.

V. To see that the levada is in proper repair, and to have repaired any wall that may have fallen over the levada, and to have removed any earth that may obstruct its course.

VI. To walk the course of the levada continually, or the part that he takes care of, to complain to his director of any theft of water, or if any damage that he can not repair.

VII. To watch the good keeping of the trees close to the levada.

VIII. To fulfill all the orders given him by the director as regards the levada.

ART. 15. The caretakers of the levadas are considered as forest-keepers, and are bound to watch the forest and bushes of his district complaining to the administrator of the locality should there be any damage to the forest.

ART. 16. The director of Levada Rabacal is bound to live close to the same levada, in one of the buildings, at a place called Rosadas, and to keep the houses clean when visitors stay there on their way to see the levada, and he is also answerable for the good keeping of the furniture, of which he has an inventory given him by the administrator, which there is a copy sent to government department of the district and one given to the caretaker of this levada. The director can have a house to live in conditional that he keep the tools belonging to the levada, and also those of the public works.

PART SECOND—TO LEASE THE WATERS.

ART. 17. To rent the water each levada must have a giro (that is a rotation of days) so that each lessee during the irrigation season shall receive the quantity of water he bargained for or bought.

The giros are fixed.—For the Levada Rabaçol is established every sixteen days or three hundred and eighty-four hours in each branch.

For the Levada of Fajã dos Vinhaticos every sixteen days or three hundred and eighty-four hours in each branch.

For the branch of Inncol and Furado, that irrigates Santa Cruz, the giro is twenty-five days or six hundred hours.

For the branch of same levada that irrigates Porto da Cruz the giro is sixteen days or three hundred and eighty-four hours.

ART. 18. The leasing the said waters shall take place yearly in the month of March in the office of the administrator of the locality in the presence of the notary of the crown, and besides these, the director and levadeiros chosen by him are to be present to give any information that may be required.

ART. 19. For the said leasing it is necessary that placards, signed by the administrator, advertising the day appointed for the lease, should be posted in the most public places of the parish and at the church doors, stating the giro of the levada and the price per hour.

A copy of these placards shall be sent to the vicars of the parish where the levada runs, to be read before the mass is celebrated.

ART. 20. The giro of the waters in each levada can only be altered by the Government after the civil governor has given his opinion and the delegate of the treasurer.

ART. 21. The price of water in each levada is annually fixed by Government, according to information given by the different functionaries.

ART. 22. The lease of these waters are made so as to include the greatest number of landed proprietors whose grounds require water, making a just and equitable distribution of it according to the wants of each individual; those that in former years rented water and paid for it have the preference, and that the quantity demanded is indispensable to the soil under culture to be irrigated.

The water can not be rented to those who are in debt for any of the preceding years.

ART. 23. The notary will take the names of all those that buy water, the quantity of hours bought, the price which the lessee has to pay, all signing a document in which they bind themselves to pay the amount as soon as it is demanded.

ART. 24. Of the document above mentioned copies are to be made so that they can be sent, one to the treasurer by post, another to the director of the levada, and two others to the levadeiros. These last need not have the amounts of money written on them.

ART. 25. The original of the above document to be kept in the archives of the Government office after the necessary papers for collecting the amounts have been made out.

ART. 26. The day on which the waters are distributed placards are to be posted in the most public part of the parish, also on the parish church doors.

PART THIRD—TO COLLECT THE RENTS.

ART. 27. The collection of the water rent of the levadas takes place in August and is collected by the tax-collector of the parish.

ART. 28. That the lessee may know when the rents are to be paid the tax-collector must have placards posted up in the most public places, at least eight days before it commences, giving notice of, first, the place where the rents are to be collected; second, the day on which he commences to receive rents.

ART. 29. The lessee who can not pay during the said period has to pay 3 per cent. on the same amount or a fixed sum of 4 cents when the said amount comes to $14. The above is declared also in the placards according to Article 20.

ART. 30. The receipts given must be according to model No. 2 of instructions published February 8, 1843.

The list must be made out according to Article 24, before mentioned, and must be in the hands of the collector before the 15th of July of each year, according to practice already established.

ART. 31. The sums received from the rents of water will be booked as "revenues of the levadas," and the 3 per cent. on fixed rate as revenues of the levadas.

PART FOURTH—DIFFERENT DISPOSITIONS.

ART. 32. The administrator has the same duties to fulfill as regards the levadas as he has toward other national properties, to see especially that the services of the levadas are properly performed by those that are intrusted with it.

ART. 33. If the repairs of the levadas be so expensive as to call for the aid of the public works, the administrator of the parish is obliged to inform the delegate of the treasury that he may ask the civil governor of the district to have the necessary repairs made.

ART. 34. The appointment of the levadeiros must be made yearly, by the administrator, during the month of February.

ART. 35. The salaries are to be paid every quarter. Other trifling expenses attending repairs to be paid at the end of each month in which they are made.

ART. 36. To pay the salaries of the employés, as well as the different items attending the levada repairs, annual pay-sheets are to be made by the administrator and sent to the treasurer to be paid.

The balance-sheets, to be paid, must be accompanied by the directors' vouchers signed by the administrator.

ART. 37. If at any season the irrigation water is not all sold, the giro can not be altered, but the administrator must let the delegate of the treasury know,

ART. 38. If at any time there is not a competent director appointed, the delegate of the treasury in the district may appoint a person *ad interim* until he gets one to fulfill the place definitely. The appointment of the director can be made by the administrator, and in that case he receives the salary of a director.

ART. 39. If the place of care-taker becomes vacant the director can appoint a person *ad interim*, until he definitely engages an individual, in the mean time he must acquaint the delegate of the treasury of the person he proposes.

ART-TRANSITORY.

To proceed with the lease of waters for the current year the price of water is as follows, subject to the approval of the Government:

In the Levada da Fajaã dos Vinhaticos and its branches, 70 cents; in Inncol branch, 60 cents; in the Furado branch, 50 cents.

If at any time the Levada da Fajaã dos Vinhaticos has not sufficient quantity of water for irrigation, for example, in the height of summer, the two branches are to be united by the mutual consent of both lessees the price then will be $1.40 each hour of water; that the lessee receives.

The other levadas are subject to the same conditions when there is a dearth of water and in that case the price is double.

HOME DEPARTMENT OF THE DISTRICT OF FUNCHAL,
March 28, 1862.

The delegate of the treasury.

FRANCISCO HAVIN DE SONTA.

Approved.

HOME DEPARTMENT OF THE DISTRICT OF FUNCHAL,
April 7, 1864.

The first official.

FRANCISCO JOAQUINN PESTANA.

REPORT OF HENRY PEASE, U. S. CONSUL, SANTIAGO, ON WATER SUPPLY AND IRRIGATION IN CAPE VERDE ISLANDS.

The subject of irrigating arid and cultivated lands in this colony is not varied or extensive enough to form the basis of a report such as requested.

Nature has been so unbounteous in her supply of fresh water to the Cape Verde Islands, that there are no lakes, rivers, ponds, or large streams, except during the rainy months, which are August, September, and part of October. But there are many springs on the islands of St. Antone, St. Iago, and St. Nickolas, issuing through the rocks at the base of the mountains, in the bottoms of the deep valleys and ravines. It therefore became necessary that the inhabitants should have settled near a spring. Yet about half the towns and villages on these islands are so remote from fresh water that all their supply is brought from 1 to 3 miles on donkeys or the heads of women.

QUANTITY AND MODE OF IRRIGATION.

It would be difficult to obtain any precise information as to the quantity of land under irrigation, as there are no reports or statistics on such a subject. Yet from observation, and information received from some land-holders, I should not underrate the areas, by stating that the only lands receiving irrigation during the dry season, which is from November to August, are a few patches of flat ground in the valleys below the level of the springs, cultivated as "garden plots."

The mode of irrigating is by making with a "hoe" (the principal agricultural implement used in this colony) a number of small trenches leading from the springs through the cultivated grounds.

EUROPE.

REPORT FROM DARIUS H. INGRAHAM, U. S. CONSUL, CADIZ, SPAIN.

I can not learn of any maps or works on the subject, though the latter may exist translated from the French, but are regarded as merely theoretical and of no interest or value to a people who have from the time of the Moors, and perhaps of the Romans, carried on practical systems of irrigation chiefly in the provinces of Murcia, Valencia, and Granada, and to a lesser extent in western Andalusia. In these provinces, especially Seville, which is watered by the Guadalquivir, whose valleys are rich not only in corks, grains, but in olives, oranges, palms, grapes, and other semi-tropical fruits, ditches are dug through the lands and fed from the river; and in other localities the irrigation is done by a sort of water raiser from wells, called norias, consisting of a chain of buckets going over and over as they come up from the well, filling and emptying by the operation, and propelled by a blinded animal, a horse, cow, ox, or mule, going round and round, and kept within the circle of the noria by a pole running from the head of the animal to the pivotal post. Thus secured he goes along all day long around the circle without driver or guide. In some cases a steam engine is in use among large properties, but the noria is of great antiquity. In Damiel, La Mancha, 3,000 norias are used, only in summer, and the same exist generally throughout Spain.

In Lorca, a town near Carthagena, where the land is salty and the river overflowed, an enormous dam has been built in recent years to retain the water.

As no statistics are published, I am unable to reply to some inquiries of the circular, but it is believed that the difference between irrigated and non-irrigated lands is as one to twenty-five in value.

There is no Government system or control custom regulating all, as it did in the time of those masters of irrigation, the Moors. For instance, at Granada a sort of court called the water court has existed by the customs of centuries, to pass on all questions of irrigation and rights between owners, and this court is regarded as high authority, dispensing exact justice and enjoying a reputation like none other in Spain. It is organized from custom; it sits at certain times at the Alhambra to hear causes, as it has done since the mediæval ages, its members coming on mules or horseback, and alighting before the bench provided for the hearings.

In one of the towers of the Alhambra a bell rings at different times of the night to indicate the flow of the waters of the Xenil and Darro, which have their confluence at this point and irrigate the vast Vega of Granada.

In this section I am not able to give the names of any experts on irrigation, as in this consular district the operations are limited as above described, but I would refer to Mr. W. Langdon, of Huelva, engineer of the Rio Tinto mines, who once furnished me an interesting paper on the teredo, a worm attacking submerged wood; and in Cadiz, Señor Don José Maria Conte, a distinguished writer and interested in agricultural subjects.

The immense importance and the successful solution of the irrigation problem implies, has justly attracted, and no doubt will always attract, a vivid attention in all agricultural countries, and as regards the European continent perhaps more especially so in Spain, where, owing to the heterogeneous character of the soil and climate, a judicious distribution and utilization of the water supplied by abundant rivers, brooks, and springs, or in certain regions, however not otherwise obtainable than by storage from rain-fall and underground sources, is, together with an obvious need, one of the most beneficial agents for general prosperity.

Water, apart from satisfying the peremptory purposes of quenching thirst, averting fire dangers, and contributing to public health and embellishment, proves a cheap and useful auxiliary of industries, but more principally a capital element, a solid guaranty to enhance and increase the agricultural production and all other interests inseparably associated with the yield of the soil, a branch that represents the most conspicuous and positive wealth.

Since in remote ages this rich and so oftentimes coveted territory entered the noble road of civilization and human progress, cultivators could not fail to become perfectly aware of the favorable influence exerted on the growth of plants, and consequently on the result of crops, through the opportune agency of irrigation, whether natural or artificial. It has been, therefore, the common aim of the Spanish people, as well as of those patriotic and enlightened rulers who have guided the destinies of the nation with a true devotion for the public welfare, to give a constant aid and all possible impulse to everything that tended to the protection and development of the water supply system.

The hydraulic works for irrigation carried out in Spain in ancient and modern times, although not yet completed to all the extent of which this country admits and even requires, show bold conceptions. They are in many cases magnificent, practical monuments erected by intelligent active minds, who thus have endowed large districts with the fruitful and lasting germ of the luxuriant life there enjoyed by past and present generations.

The treatise on "water and irrigation" (Aquas y Riegas, two volumes), which, as instructed by circular of May 2, 1889, I have the honor to send the Department of State with the present report, will, I am confident, afford useful information to the special committee appointed by the United States Senate to investigate into the matter of irrigation as practiced in Spain, and perhaps excuse diverse omissions I may incur.

While I respectfully call the attention of the Department upon said book saying that it is the only work published in this country which in every direction treats the subject in a reliable and exhaustive manner, I beg to mention that its author, Mr. Andrés Plaurado, is the chief forestry engineer for the district of Madrid and a qualified authority, both at home and abroad. He recently, in the name of the Spanish "Ministerio de Fomento" (the department embracing public works, agriculture, industry and commerce), took part in the discussion held at the International Congress of Paris on the utilization of the water of streams.

His views upon the subject "*De l'avenir des canaux d' irrigation*," remarkable essay, met the approval of eminent foreign scientific men.

Mr. Llaurado's work, "Water and Irrigation," contains an elaborate historical and technical description of the canals and reservoirs built in Spain; also useful suggestions, resting upon his practical observations, concerning construction, financial and economic results, and the best means to secure the success pursued in enterprises for irrigation.

First of all, I will now point out the prominent conclusions arrived at by Mr. Llaurado, namely:

It is an axiom that in northern countries irrigation increases the product of cultivation, especially in summer.

In southern countries irrigation becomes absolutely necessary, whether to remedy drought or to overcome the consequences of unequal rain-fall.

Reservoirs become absolutely necessary in Spain to store up water during the time there is rain, in order that the decrease produced in streams just when agriculture is most in want of it might be restored.

Irrigation undertakings must divide in two different classes:

(1) Irrigation works which can be achieved by the single individual effort.

(2) Irrigation schemes which necessitate the interposition and subsidies of the Government.

Private activity, from a financial stand-point considered, will be able to accomplish irrigation schemes, provided the rate consumers pay for water covers the expenses of working them, the amount of interest corresponding to capital invested, and a fair profit. Otherwise the business must result in a failure for private concern, while, though it can not be absolutely asserted, it is advantageous for the Government, whose ample unlimited means of action allow them to balance loss with profit.

What now is met with at the "Canal Imperial de Aragon" and at the "Canal de Urgel," under direct management of the public administration, clearly evidence that assertion. The construction of the first-mentioned canal cost the Government about 20,000,000 pesetas ($4,000,000), and since the reign of Carlos III, when it began to be worked, up to our days the immediate direct net produce earned by the administration aggregates the sum of 37,000 pesetas annually ($7,400), a notorious meager yield in proportion to the capital invested.

But the business, however, far from being ruinous for the State, has largely compensated the outlays by creating great sources of wealth, which deliver up to the public treasury a good part of their income.

It must not be overlooked that, in order to render mutually advantageous to companies and farmers the utilization of water schemes the irrigation tariff must be rated cheap.

The modest yet mighty sphere of private spirit is able to achieve with success many works in totality superior to the limited number of enterprises due to the initiative of the Government.

That does not mean the Government should be allowed to monopolize this kind of undertakings. They are not feasible for the Spanish Treasury in its present circumstances, when it is rather too much influenced by the oscillations of politics.

But the administration can promote such irrigation business as may aid the private companies by affording facilities to individual action, by making public the hydrological data, the investigation of which is not consistent with private initiative, and by framing accurate statistics on the rights for use of available public water.

As refers to the great works of canalization the Government ought to undertake the construction for its own account, and when they are finished cede them on fair terms to the irrigation syndicates, reserving

itself the right of superintendence and protection, in order that the sacrifices made by the people may not result fruitless.

The Spanish Peninsula extends approximately over eight latitudinal and upwards of twelve and one-half longitudinal degrees; its periphery measures 3,300 kilometers; the surface of its soil comprises about 50,000,000 hectares (123,500,000 acres), with elevations exceeding 3,500 meters above the level of the ocean, vast table-lands, deep valleys, and nearly 2,000 kilometers sea-shores extending along four slopes, washed by different seas, and facing different cardinal points of the globe.

The contrasting conditions of climate enjoyed according to local circumstances can well be imagined; they are so manifold that in this sense, rather than a mere peninsular, Spain comprises by itself a vast continent joined to the rest of Europe through the mountain range of the Pyrenees, and partakes the scale of subtropical up to sub-Alpine temperature, with burning summers, as in the Sahara Desert, or glacial winters, as in Scandinavia. A glance at the hereto appended summary of meteorological observations gives a fair idea on the physical consequences which arise in various regions.

In the qualities of the soil all gradations exist, from the hardest and most compact clayish soil to that of the most loose and movable silicious nature, in all possible shapes, the evenest as well as the steepest and most rugged. It also differs in depth from the shallowest and most naked soil up to the most covered with vegetable layers; and as to the hygrometrical conditions from extreme moisture to the most complete dryness, from the least fitted to irrigation, and to such as is perpetually condemned to receive no other water than from rain-fall.

Of the total area of Spain (50,000,000 hectares) 40,000,000 hectares are cultivated for crops and pastures; about 2,000,000 thereof are benefited by irrigation.

Among other peculiar features common to the north coast of Spain the provinces of Santander, Oviedo, Biscay, and Guipuzcod, in which this consulate and its respective agencies of Gijon, Bilbao, and San Sebastian are located, partake of the most frequent and greatest rainfall in any part of the Spanish peninsula or in Europe.

I quote what Mr. Llaurado says, referring to the above-mentioned provinces:

> On account of the great moisture, the air being almost always in a state close to saturation, ordinarily no other farming grounds but the meadows require a supplettory irrigation. In comparatively dry summers, however, some orchards will be irrigated, principally on alluvial soils of new formation where the underlying stratum, consisting of loose pebble-stones, allows an easy permeability. Permanent meadows constitute the main basis of the agricultural wealth, for they are calculated to supply food for 400,000 heads of horn cattle and a good number of horses and sheep besides, as refers only to the province of Oviedo, and nearly equal proportionate ciphers are applicable for the remnant three provinces, especially for Santander.

In order to examine the cultivation of meadows as it is practiced here, we must suppose them divided in two groups, namely, irrigated and not irrigated meadows.

The first ones are generally lying on the declivities or on the valleys, in the neighborhood of some spring or brook, the water of which may be easily drained; and the last-mentioned meadows occupy the table-lands on the tops of mountains and all such places not much accessible for irrigating them by artificial means, which enjoy no other irrigation but that imparted by eventual rains.

The irrigated meadows, in their turn, form two groups, in the first of which are included those the products of which are consumed by cat-

tle on the meadow itself, the summer harvest excepted, this being mowed and stored for stable food. In the second group are comprised the meadows the produce of which is mowed and cattle fed therewith when yet green, and which furnish, besides, the summer harvest like the meadow lands of the first group. In these irrigations last during all the year, and are only discontinued as long as the cattle are kept within the stable, this being done the months of April, September, and October, on fine days in winter, when tardy frosts are feared, and during twenty to thirty days before harvesting the hay.

Not irrigated meadows, in spite of the moist climate, yield considerably less than the irrigated ones, irrigation being, therefore, indispensable if it is desired to obtain abundant pasture and hay.

The remark has been already made that the water used for this kind of cultivation is either drained from brooks or from little perenninal springs, as well because of the continuity and facility of their utilization as on account of the difficulties met with in the drainage from streams, the most part thereof offering deep beds and an excessive slopeness.

The system for irrigation of meadow lands most commonly applied in these provinces is that denominated "irrigation by inclined channels," or also "spike channels" (*riego por regueras inclinadas* or *regueras en espiga*). The distribution channels are devised nearly in the sense of the greatest slopeness of the ground; the irrigating channels connect with them and spread out to right and left hand.

A rapid sectional change takes place on the distribution channels at the point where they separate into branches with the irrigating channels. The last-mentioned channels, by having a gradually narrowing section from their parting point down to the opposite end, pour out the water by getting inundated. Another contrivance is also combined with this briefly described distributive system which consists of collecting channels called *azarbes*, dug on the natural lines of junction on the meadow ground terminating in an outlet channel. Sometimes, when the extent of the meadow is not considerable, or when the quantity of water available is but small, the collecting channels are changed into new feeding channels for the supply of other lots situated farther down.

Within the four provinces above named discrimination of three different climates and regions must be made, depending from situation, whether on the sea-shore, inland valleys, and mountains. The climate on the sea-shore is mild; orange trees can thrive in the open air. In the valleys the climate is fresh; there orange trees, as also grape-vines, only thrive on sheltered places. The climate on the mountains is cold; they generally in winter are covered with snow. Here lies the center of the Cantabrian Mountains, a branch of the Pyrenic Mountain range, with lofty summits, some of them as high as 2,678 meters above the level of the sea.

The highest temperature at the inland valley of Cabuerniga, Santander, during a period of three years (1872–1874), as recorded by the foresty engineer, Mr. Louis Calderon was 48° heat in the sun, 39° in the shadow, and the lowest, which, like the other extreme temperature, very seldom occurs, was 4° below zero. Many years the temperature never exceeds zero degrees. When the thermometer points out 8° or 10°, water generally falls on the mountain pastures lying highest, called *puertos* or "harbors," in the shape of snow.

The forestal and cattle raising industries are the most genuine and prominent riches in these provinces, especially in Oviedo and Santander. The structure of the soil consisting of narrow valleys surrounded by

mountains with varied but for the most part too steepy slopes for a safe and commodious cultivation, it is obvious to say that the agriculture, limited to valleys and flat lands of small extent, can never attain a great developement. But, in exchange for the forest and cattle interests, there is proportionately immense room in the best conditions for success, as the frequent rain and continuous mists, covering almost constantly and at all seasons of the year those mountains, maintain a most suitable, fresh, and moist character to vigorous spontaneous vegetation.

The communal pasture grounds being abundant and of such good quality, natural meadows are, most of them, intended to harvest fodder for feeding the cattle during the time the atmospherical inclemencies hinder a direct grazing. As the period when this occurs is no longer than three or four months in the year, the cattle-raising industry is certainly susceptible of a far greater increase as soon as the meadow lands are more carefully cultivated and larger quantities of hay are produced. With the quantity of fodder indispensable for a head of cattle in other provinces, three heads will then be fed here, because the period cattle have to be kept in the cow-house is much shorter. A permanent keeping in the stall is not advisable unless the absurd principle should be established to abandon the enormous wealth the beautiful and vast grazing grounds of the high meadows (*puertos*) represent.

The system now partly prevalent in cattle-breeding is of course such as arises from the local conditions; in the West region born-cattle are raised until two years old, whereupon farmers in the East region and on the sea-shore devote themselves to raise the same up to full growth. In the first-mentioned region natural as well as high meadows (*puertos*) are abundant, while in the other parts that kind of meadows are scarce, and consequently cultivation-meadows become necessary.

One should think that in the Cantabrian coast, one of the rainiest countries of Europe, the system of drainage, rather than that of artificial irrigation, would often be applied. Yet irrigation is here of no little importance, mainly to obtain natural meadows and repair the irregularities of meteoric water used for other cultivators.

Irrigation is most frequently made use of here during the months of March and April, when grass begins to shoot up. The soil is left altogether inundated when strong frosts are feared, in order that the covers of water might protect the soil against the consequences of frost or ice. In normal years artificially irrigated meadow-lands produce greater harvest than those called "*praderas de secano*" or "dry land meadows," but in exceptional years of drought the irrigated meadows are the life-boats wherein farmers save their cattle.

Milk, so its products, butter and cheese, all of an exquisite natural flavor in these provinces, it can be affirmed, have no rival of higher standard in the world. It is obvious to reveal the secret of such excellent qualities, which consists in nothing else besides a good cattle race but the conditions of plenty of pure air and nutritive aromatic pastures. The cow breeds called "of Tudanca" and of "Campoo," in the neighboring districts of Cabuceniga and Régnosa, respectively, Santander, and the "Asturian" race, province of Oviedo, justly enjoy a great renown.

For centuries the mountain woodlands of Santander have been providing with superior timber (oak) the Spanish navy and merchant shipyards, also (beech) cooperies for preparing barrels or casks for wine and wheat-flour exportations to the Antilles. They scarcely have escaped the total devastation that has been the fate of public forests in Spain.

The planting of trees to replace those consumed or cut from the parish forests was formerly compulsory for all citizens who enjoyed the rights to use the same. That duty is completely neglected; though it has not been repealed, it is not enforced as it ought to be.

I have thought it pertinent to make some digressions on the circumstances attending agriculture and cattle-raising, those two branches which form the great wealth of the mentioned provinces, because of their being so closely connected with irrigation.

On the whole, the geological and climatic conditions in this northern part of Spain keep the greatest resemblance with the counties comprising the "wealden formation," in the southeast of England, such as Kent and Sussex.

An agent which considerably modifies the damp character of this climate is the south wind. It acts like an enormous sponge to absorb the humidity, and as a natural stove where both the air and the soil are speedily dried up. The atmosphere acquires then such transparency that scarcely any gradual lines or shadows of varying distances on the horizon are perceived. It is peculiar to the south wind that immediately it ceases to blow it is generally followed with rain, and that while it is blowing on the coast, rain will most likely be falling on the elevated plateau of Old Castile. The winds which prevail longest in the year come from the west-northwest, succeeding the periods from the south. The east-northeast winds are those blowing in summer until September or October, when they maintain clear, dry weather for longer time.

In the provinces of the North, adjoining those where this consulate and its agencies are situated, irrigation by artificial means is practiced, more extensively at Leon, which borders on its northwest side with Santander and Oviedo. The Ecla Canal irrigates there about 13,000 hectares (32,125 acres). When its construction began (1859), the estimates amounted only to 625,000 pesetas ($126,000), but ten years later (1869) the sum of 3,250,000 pesetas ($650,000) had been expended. It carries a quantity of 6,480 cubic meters water per second. This canal was built by grant to a foreign private company. According to agreement the annual rate farmers have to pay for water varies from 19.45 pesetas to 97.27 pesetas ($3.89 to $19.45) for each hectare of land irrigated. Notwithstanding the yearly aggregate cashed by the company has been about 8½ per cent. on the capital invested, it does not produce sufficiently to pay the interest to capital, the expenses of maintainance, management, and of interest necessary for amortization. The company met with some embarrassment, perhaps, by not having secured through a formal written engagement how far they had to rely upon consumption of water. Until a year when extreme drought prevailed in the country, the attitude on the part of many farmers to subscribe for the use of the water for this new canal was quite reluctant, but then they obtained a practical conviction of the positive advantages derived from artificial irrigation to supply the absence of rain.

On the vast plateau of Old Castile the "Canal de Castilla" crosses a distance of 207.792 kilometers from Alar del Rey, Santander, dividing in two branches at El Serron, Paleucia; one of them, the "Canal del Sur," 54.432 kilometers long, down to Valladolid, and the other, the "Canal de Campos," 78.929 kilometers long, to Medina de Rioseco," the center of cereal production in the North, called for this reason, by Spaniards, "*el granero de España*," or "the corn-barn of Spain." The section of the "Canal de Castilla" from Alar del Rey to El Serron takes the denomination of "Canal del North," and is 74.431 kilometers long.

The "Canal de Castilla" is an important water-road for transporta-

serves also as a motive force for a good number of large mills and factories. But the same is scarcely used as a means of artificial irrigation. Its most noteworthy works are seven locks on the "Canal de Campos," twenty-four on the "Canal del North," and seventeen on the "Canal del Sur."

On the "Canal del Norte" section, the canal carries 4.47 cubic meters water per second, being distributed between the two branches in the proportion of 2.79 cubic meters to the "Canal del Sur" and 1.68 cubic meters to the "Canal de Campos." The uppermost part of the canal in the last-mentioned section is 15.55 meters wide, at the surface of the water 11.66, and at the bottom of the canal 5.83 meters wide; it has a depth of 1.93 meters. The towage-path along the canal measures 3.33 meters width in places where the earth had to be cut off, and 4.44 meters at the embankments.

The Pisuerga and Carrion affluents of the river Duro, are the feeders of the "Canal de Castilla," the construction of which, begun in the middle of the last century, was interrupted, and reached its completion during the reign of Queen Isabel II.

In normal years the want of moisture necessary to the growth of most cereals, wheat, barley, rye, etc., seems not to be much felt on the boundless-looking corn-fields of the northern provinces of Castile. The arable surface of the soil is deep and fertile, though the monotonous perspective of vast plain land impresses the mind with aridness, seeing that it is almost completely denuded of trees everywhere, for the prejudice is most prevalent there among cultivators "that trees are only good for sparrows to build their nests on and as places of shelter for the voracious winged enemies of plantations."

During the war of Crimea the shipments of wheat-flour from Castile, made at the port of Santander, amounted to enormous quantities. An enthusiastic fever then existed throughout Castile. The boasting phrase, "*Agua y sol y guerra en Sebastopol,*" ("Water and sun besides war at Sebastopol,") whereby Castilian farmers expressed their prosperous situation in those years, was so generally pronounced and repeated that it became a proverbial sentence.

A great number of flour-mills were erected on the canal, and the largest possible extent was given to the production of cereals. Those exceptional incidental causes by which the agriculture was favored have passed long ago; they are now not more subsistent. Farmers in Castile devote their care not only to cereals, but also to extend the grape-vine plantations, and must adopt all improvements in modern agricultural progress if they will keep pace with the cheap production of other countries. Irrigation will be of course a means to the profitable result of a varied cultivation.

The province of Logroño bordering with the back province Alava, is one of the agricultural districts where great benefits are obtained through artificial irrigation that makes it very productive in all kinds of fruits and vegetables. It is the richest orchard and kitchen garden in the northern region of the river. Elbro, the source of which is at Fuentibre (Fons Tiberus), near Reynosa, Santander. This river becomes navigable at Saragossa, supplies water for the "Canal Imperial," and some other of the most important irrigating canals, and no other river in Spain is more used for irrigation; the advantages it affords to agriculture are considerable.

At Logroño and the neighboring districts known all under the denomination of "La Rioja" good wine is obtained and mostly exported

to France, and also shipped to other countries by Bilbao and Santander. Fruits and vegetables (capsicum, tomatoes, peas, etc.), are prepared in cans in important quantities for house and export consumption.

The practical and wise laws founded or issued by the Arabs during their domination in the south of Spain, in the provinces of Valencia, Murcia, and Granada, maintained there more specially by careful traditions, are the basis of the new laws framed for all irrigating corporation, who will enjoy certain privileges. These privileges consist substantially in the right that when as prescribed they unite in "Sindicatos" or syndicates, they can appoint their own independent courts, all proceedings being public, verbal, and the decisions of these independent courts (*Turados de Aguas*) or water-juries inappealable.

In Leon such syndicates exist, so in Logroño, but in none of the above-mentioned provinces of the North, where, for the reasons I have explained, artificial irrigation exhibits an individual, isolated aspect.

Engineers in the construction of some of their great hydraulic contrivances do, perhaps, only observe and copy the works of nature. There are no "lakes" formed by rivers in Spain to collect water for further distribution in "natural deposits;" to supply the same on suitable elevated places, sometimes in the mountain gorges, reservoirs, called "albuheras" or by the more modern name "pantanos," are built, where the water is stored up. *Acequia* (as many words of Arabic source) means exclusively irrigation canal.

In Valencia farmers have inherited with the valuable irrigation system of the Saracens also their good practical habits for agricultural. There they know what great value water involves. They always carefully look that the ground be well leveled in order that both the water coming from canals and from rain-fall is equally beneficial to the plants, because otherwise some parts of the soil will become covered with water while other parts remain dry, and in some others water will carry away the humus, salts, and oxides, the richest elements contained in manure to aid vegetation. Nobody knows as they do to retrench the flowers and buds when the plants are too overcharged, as they are aware that a smaller number makes fruits get ripe earlier and improves the quality. Nobody else knows better than those farmers how to select the precocious ears, one by one, with the purpose of ameliorating the species and accelerating the period for ripeness. The Valencia farmers remain constantly near their plantations, and through artificial irrigation they realize in that climate an abundant and incessant crop of rich products.

REPORT FROM J. L. RATHBONE, U. S. CONSUL-GENERAL, PARIS, ON IRRIGATION IN FRANCE.

(1) Areas of land under irrigation; compare with the non-irrigable and cultivatable areas when possible. Also, quantity and quality of crops grown?

The surface of irrigated lands is roughly estimated at 2,350,000 hectares. As cultivated lands are not generally irrigated, it is not easy to compare non-irrigated with irrigated lands. Pastures are the only lands generally irrigated.

The average production per hectare of irrigated and non-irrigated pastures is: Irrigated pastures, 37 quintals; non-irrigated, 31 quintals. This difference of 6 quintals represents a total value, in the first case, of 230 francs; in the second, of 190 francs, per hectare. Among the

areas devoted to cultivating the vine, some are submerged, while others are irrigated. But the value of their produce depends upon other causes than irrigation.

(2) Sources of water supply, whether from rivers, streams, springs, lakes, wells, reservoirs, catchment basins, or tanks, etc.

The canals cut for purposes of irrigation all flow from rivers. In some instances attempts have been made, by means of artificial reservoirs, to increase the quantity of water yielded by the river. It was for this purpose, for example, that the reservoir of Oridon was constructed in the department of the Hautes Pyrénées. Its object was to increase the volume of water in the river Neste, from which flows the canal of the same name.

(3) Character of works used for storage and distribution of water. Forward published reports, if obtainable, in regard to any important irrigation and storage works.

The number of reservoirs above mentioned is still somewhat limited. The works carried out in view of distributing the water generally consist, first, of a principal canal, or chief branch through which the volume of water to be distributed flows from the river; second, of a small canal, fed by the principal one; third, of a net-work of streams, drains, and ditches which provide each land-owner with the quantity of water to which he is entitled.

(4) The system of water distribution, whether governed by laws, rules, and regulations, or customs, give duty of water per acre, *i. e.*, the amount used per acre and per season; the cost or rental to user; tenure of ownership of water, and whether the same be public or private, national or community.

The use of water for irrigating is regulated by the French code. The articles of the code bearing particularly on this point are the following:

643. The owner of the spring can not change its course when he provides the inhabitants of a commune, village, or hamlet with the water necessary for them; but where the inhabitants have not acquired or prescribed the use of the same, the owner may demand a compensation, the exact amount of which is to be fixed by an expert.

644. The owner of a property skirted by a running water which is not national property, according to article 538, has a right to the use of the water for irrigating his lands while it flows past them. The owner of ancestral lands traversed by this water may use it within the full limits of his lands, on condition he restores it to its proper bed before it leaves his estate.

645. If a dispute arises between the land-owners to whom this water may be useful, the tribunal called upon to give its decision in the matter shall conciliate the interests of agriculture with the respect due to the rights of property, and, in every case, with the particular and local customs and regulations which pertain to the passage and use of water.

The works executed for purposes of irrigation may be divided into two classes:

(1) Those undertaken and carried out by companies called syndical associations.

(2) Those undertaken and carried out by a contractor.

When a syndical association carries the work into execution, its statutes usually determine on what lines the distribution of water shall be regulated. But when the works are taken in hand by a contractor, the distribution is fixed, either by a decree published after the council of state has recorded its decision, or by a decree signed by the prefect or chief magistrate of the department in which the works have been, or are to be, executed. The prefect is empowered to sign these decrees since August, 1886.

The syndical associations are composed of land-owners whose inter-

ests are affected by the want of irrigation. Their powers, privileges, etc., are more or less determined by common law.

The French Senate is at present discussing a projected rural code, which will contain a certain number of articles relative to irrigation.

In a general way the quantity of water required to irrigate a hectare is equal to an outflow of one liter per second all the year round. The cost per hectare is apt to vary considerably if the works are executed by a syndical association. In that case the average cost may be set down at 40 francs per annum for a supply of water equal to about 1 liter per second. If, on the contrary, the works are carried out by a contract, the cost is always a fixed one, it can never vary, inasmuch as it has been determined by the deed of concession.

The following table shows the figures of the tax raised for some of the leading irrigating canals:

Canals.	Departments.	Cost.	
		A.	B.
		Francs.	*Francs.*
Pierrelatte	Drôme, Vaucluse	50	60
Bronne	Drôme	50	60
Visubie	Alpes Maritimes	80	.....
Verdun	Bouches-du-Rhône	70	.....
Saint-Martory	Haute Garonne	35	50

When two figures are given for a single canal the figures in column A show the tax due by the land-owners who subscribed before the water of the principal canal (see Answer 3) was turned into its destined channel, while the figures in column B denote the amount paid by those who subscribed afterwards. In the case of the last-mentioned canal, the figures shown in column A, the sum paid by land-owners who subscribed before the deed of concession was promulgated, and in column B the amount paid by those who subscribed after its promulgation.

Springs only may be owned either by private individuals, by the state, or by the small districts called communes.

Running waters are considered *res nullins*, but the use of them is regulated according to law on the non-navigable water-courses.

The water of navigable water-courses is considered national property.

(5) Character of climate in irrigated region, and nature of soil, annual rain-fall, and other precipitation.

Although the practice of irrigating is as widely spread in the north as in the south of France, it is chiefly in the regions bordering on the Mediterranean, where the summer rains often fail, the most important irrigating canals have been cut. In the north, east, or west the works designed to promote irrigation are nearly always carried out by private individuals. This is especially the case in the department of the Vosges. In the south they are, for the most part, the result of the combined efforts of a certain number of individuals. They are mainly undertaken where the soil is of a chalky nature and in lands formed by alluvium.

Among the systems adopted to distribute the water may be mentioned an interesting one practiced in the department of the Bouchesdu Rhône. It is a kind of irrigation by submersion. The lands subjected to this method are constantly increasing in extent.

The land owners whose properties are situated on the banks of the Rhône obtain, when they require it, and by means of elevating machines, the quantity of water necessary for the process of submersion, which lasts

sixty days and consumes not fewer than 1,500 cubic meters per hectare. The estates in the center of the island of Camargue, in the same department, are less favored than those seated on the river banks. The water has to be conveyed to them from the river by means of small canals and side channels, which generally belong to syndical associations of a very remote origin. These side channels work during the rising of the Rhône. As, however, the frame-work of their flood-gates is almost on the same level as the low-water mark of the river, when it is not higher, it often happens that, when the Rhône is low, the side channels become dry. Besides this, the season for submerging the land often coincides with this autumnal fall of the river, and irrigation is practically brought to a standstill.

Numerous plans have been formed to find these side channels by means of large canals cut in the north of the island. But none of them have yet been carried out. Pending the execution of a plan a society of land-owners, headed by the Count of Chevigne, recently set an example well worth following. Their project is not less remarkable for the way in which it was conceived than from the results which may be expected from it. They are thirteen in number, and their combined estates contain some 1,500 hectares. In order to keep their side channels constantly supplied with water they applied to several mechanical engineers for machines, and finally adopted an apparatus presented by one of them, and which has given the most satisfactory results.

Its characteristic feature is that instead of being a fixture it floats and can be conveyed from one place to another. Thus it can be made to work anywhere. It consists of a boat built wholly of iron, and equally adapted to fluvial and maritime navigation. Its length is 24 meters; its breadth 5 meters; and its draught of water nearly 1½ meters. It carries three engines on the compound system in juxtaposition, and of 200 horse-power. Two of them each turns a rotary pump by bearing directly on its beam. The third, which can be made to work either of the two pumps, is used only when one of the other engines is out of order. On the one hand, these machines are condensing engines; on the other, their steam is provided by boilers on the Bigot system. These latter are used in the French Navy, and possess a collective warming surface of 80 square meters. Their consumption of fuel is therefore comparatively small. The pumps fixed up on board are on the Decœur system. They raise the water from a depth varying between 1½ and 2½ meters, according to the level of the Rhône, and distribute the water at the rate of from 750 to 1,500 liters per second.

The following table gives more ample particulars. To understand its figures rightly it is necessary to know beforehand that they are given when both engines are working together and distributing 500 liters per second:

Height above river.	Horse-power.			Number of turns.	Consumption.	
	In quantity of water brought up.	On the beam of the pump.	On the sucker.		Total per hour.	Per horse-power of water brought up.
Meters.						
1.00	15.0	24	32	140	35.20	2.340
1.50	22.5	36	48	150	46.86	2.348
2.00	30.0	48	64	160	70.40	2.340
2.50	37.5	60	80	170	88.00	2.340

When the pumps distribute 1,500 liters instead of 500, these figures remain proportionately the same. The suction is performed in a special division provided with vases, and the water is thrust back into a collecting pipe which serves for both engines at the same time the boat is working; it is moored on the spot from which the water is drawn up. The collecting pipe has a weir provided with a slat spout. It runs into a sheet-iron reservoir placed at the head of the side channel and outside the river dam. The connecting of the weir with the collecting-pipe is accomplished by means of a link with a hinge to it which enables the spout to remain constantly in position on the edge of the reservoir, whatever the motion of the boat may be. By this arrangement the work done by the pumps is limited to a height corresponding with the difference in the level of the water, and with that fixed for submerging the land. This second level is slightly below the height of the reservoir itself.

The annual rain-fall for all France is estimated at about 77 centimeters.

(6) Antiquity or otherwise of irrigation systems within the section treated of, and whether the same are maintained at public or private expense?

The cutting of a certain number of canals for irrigation in the southern districts dates from several centuries. The more important works, however, are of comparatively recent origin. During the last ten years, especially, a great impulse has been given to the construction of works devoted to irrigation. Subjoined is a list of the most notable enterprises of this kind. It is taken from the "Journal d'Agriculture pratique."

Departments.	Description of works.	Cost.
		Francs.
Drôme	Canal de la Bronne	13, 000, 000
Alpes-Maritimes	Canal de la Vésubie	7, 000, 000
Aude and Hérault	Canal to be used for submerging both departments	2, 400, 000
Drôme and Vaucluse	Canal de Pierrelatte	8, 000, 000
Basses-Alpes	Canal de Tranasque	4. 500, 000
Hautes-Alpes	Canal de Ventaron	2, 000, 000
Aude	Canal de Canef	1, 000, 000
Bouches-du-Rhône	Drying up the Fos Marshes and purifying the waters of the Cran.	18, 000, 000
Hérault	Canal de Gignac	4, 200, 000
Loire	Canal de Farey	7, 000, 000
Alpes-Maritimes	Canal de Toulon	1, 200, 000
Aude	Canal de Cuxac	2, 000, 000
Do	Canal de Sue	1, 160, 000
Do	Canal de Fabrezarn	

The public treasury generally contributes one-third of the costs of the works; the land-owners interested in them defray the remaining two-thirds. In the case of the most important works, the state, besides contributing its third, has guarantied for the space of fifty years, to the parties who covered the loans raised for the purpose of carrying out the works, the interest due on the sums lent to the contractors.

TRANSLATION BY UNITED STATES CONSUL DUFAIS, OF HAVRE, OF A LETTER ON IRRIGATION FROM MR. LUCIAN, CHIEF ENGINEER OF ROADS AND BRIDGES, DEPARTMENT OF CALVADOS, FRANCE.

CAEN, *August* 30, 1889.

SIR: I beg to answer in the following order the several questions asked in your letter of the 8th instant:

(1) Calvados being a cattle-raising country since a long time, the utmost has been done to utilize the water. The new demands for irrigation are therefore very rare, and it is to be supposed that the surface of the irrigable lands is already under irrigation. This surface, according to a statement made in 1870, was only 1,372 hectares (3,390 acres). This small proportion of the surface of the department which contains 552,000 hectares (1,364,544 acres) is explained by the dampness of the climate, which rather needs being made salubrious by drainage of marshes, etc., than by irrigation.

It is important to note that nearly 20,000 hectares (49,440 acres) are irregularly watered by flood or wild waters.

Artificial irrigation is exclusively applied to permanent meadows.

(2) The water used for irrigation comes exclusively from the streams.

(3) The works constructed on streams for the distribution of the waters used for irrigation generally consist of bars fitted with water-gates able to be lifted above the highest water. These bars are authorized by a prefectoral commission prescribing the dimensions and dispositions. Moreover, everybody may after an administrative inquiry obtain the authorization of using a stream of which he is a borderer, said water, after he has used it, to be returned to its natural course, under all reserves, however, of the rights of third parties.

(4) Nearly all irrigations in Calvados are of a private character; there are none of a collective use to report but two.

Irrigation of the small valley of Aute (arrondissement of Falaise). A decree dated February 11, 1881, rendered after inquiry, has authorized and located the establishment of 16 bars constructed in the River Aute. A prefectoral decree settled the dates and hours of irrigation for each bar. The surface of the land to be watered is 152 hectares (376 acres).

Irrigation of the valley of Orber within the limits of the department at Lisecua. It is not a question in fact of irrigation exclusively. The land proprietors joined in a syndical association to secure on one hand the irrigation of 286 hectares (707 acres) of meadows, and on the other the working of the numerous factories situated in an industrious valley, where there are at least 85 streams and brooks. This syndicate is regulated by a decree dated June 18, 1864, which stipulates the use of the waters and settled the dates and hours of using the water, always considering the wants of the factories.

A syndical commission, whose members are appointed by the prefect (according to the statutes), manage gratuitously the interests of the association, the expenses, etc., by means of a roll rendered executory by the prefect and which is collected by the "receiver of finance" of the district, commissioned to that effect. By means of this roll the expenses are apportioned between the interested land-owners in proportion to the value of their property. There are no fees for the use of the waters, which are common property of the adjoining landlords.

The syndical associations established previous to 1865 are under the rules of the law dated June 21, 1885, modified by the recent law dated December 22, 1888.

(5) Climate damp; the yearly average rain-fall is 700 millimeters (27½ inches).

Calvados soil, heaths and waste lands, 12,000 hectares (29,664 acres); rich soil, 150,000 hectares (370,800 acres); calcareous soil, 150,000 hectares (370,800 acres); gravel soil, 8,500 hectares (21,212 acres); stony soil, 5,000 hectares (12,360 acres); sandy soil, 2,500 hectares (6,180 acres); marshy soil, 70,500 hectares (174,276 acres); diverse soils, 173,300 hectares (429,092 acres).

The most part of these soils is divided as regards agricultural purposes in 317,000 hectares (783,624 acres) arable lands, and 141,000 hectares (348,550 acres) of natural and artificial meadows.

REPORT OF CHARLES B. TRAIL, U. S. CONSUL, MARSEILLES, ON IRRIGATION IN THE DEPARTMENT DES BOUCHES DU RHONE.

Metric denominations and their equivalents:

Meter equals 39.37 inches.
Hectare equals 2.471 acres.
Liter equals .908 quart, dry measure.
Liter equals 1.056 quart, liquid measure.
Hectoliter equals 2 bushels, 3.35 pecks, dry measure.
Hectoliter equals 26.44 gallons, liquid measure.

Much attention has been given to irrigation in France during the past century, and the Government has from time to time sought to increase the public interest in this most important subject by publishing scientific reports on the same, and, more recently, by instituting "concours" and offering prizes to those adopting the best methods and securing the best results from irrigation. In the north of France irrigation is accomplished by simply inundating the land, and is confined principally to submerging meadow lands in the autumn by turning off large quantities of water from the rivers and streams; in the central portion, by the use of water from springs and wells distributed over the land by hand and machinery; and in the south province, the Department des Bouches du Rhone and its neighbors, by irrigating canals.

Irrigating canals of any importance are confined to the valley of the Rhône, the foot of the Pyrénées, and to only a few other localities in France. The canals of northern and central France are only used for transportation.

Given sufficient water there is no reason why a canal should not serve for both transportation and irrigation. This is done in Italy with the addition of obtaining motive power from the current as well; but in France the canals only fulfill one function at a time with but a few exceptions.

The use of canals for irrigation is of very ancient date in France. The first canal in Provence that we know of was constructed by Marius, the consul, in 103 B. C., for the purpose of transporting supplies to the Roman army, then encamped near Arles, and it is probable that it afterwards, when abandoned as a water-way, served to irrigate the land contiguous with it. Arthur Young, traveling through Provence towards the close of the last century, was particularly interested in the irrigating canals he there saw, and expressed his surprise that other parts of France did not imitate the Midi in this most important of rural economies.

Irrigation of some sort is indispensable in the Midi. Without its aid agriculture would have to be abandoned. Three months and occasionally nine pass by without rain-fall. The summers are long and the heat great and continuous, while the sun shines through an intensely pure air, unobscured by a single cloud, subjecting the land day after day to a constant drying and scorching process and causing every particle of humidity to evaporate.

The department des Bouches-du-Rhône, to which the report is limited, forms the southeast of France bordering on the Mediterranean and, as its name implies, comprises the territory surrounding the mouth of the Rhône. Its northern boundary is the river Durance, which, rising in the Alps, flows westwardly and empties into the Rhône not far below Avignon.

From the Durance the irrigating canals are principally drawn. The area of the department is 510,487 hectares. The entire surface artificially watered embraces 35,091 hectares, and of this the Durance contributes water for 26,880 hectares, or—

	Hectares.
Irrigation from the Durance	26,880
Irrigation from Huveaune, Arc, La Touloulu, etc	2,911
Irrigation from the Rhône	5,300
	35,091

A glance at the map on page 12 of the "Rapport sur la Concours ouvert en 1875," accompanying this report, explains why it is that the Durance has been so heavily tapped to supply irrigation for this department.

Provence is composed of mountains, hills, and plains. The greater part of the soil is naturally very poor, it being detritus brought down from the Alps by the Durance, and in flood-time spread over the plains. Strong winds sweep over it at times. The soil naturally produces only stunted trees and coarse grasses; but by irrigation and the liberal use of manure a maximum of fertility is obtained where from the want of water absolute sterility reigned.

Geographically speaking, the department des Bouches-du-Rhône presents three distinct features. First. A mountainous section to the north and east, composed almost entirely of limestone of a dull gray color and in part quite naked of vegetation, and in part covered with wood. Streams from the mountains descend to the Durance, to the Rhône, and to the Mediterranean. Second. Two plains, la Crau in the center of the department, very stony, and la Camarque to the west, composed of mud and sand. Third. Marshes and ponds, shallow reservoirs, whose waters flow slowly to the sea.

There was an old French proverb that said Provence had three curses to contend with: Parliament, the river Durance, and the mistral. Parliament was swept away by the revolution. The Durance, whose waters at times overflowed its lands and carried destruction in their wake, has been tamed by man's ingenuity and from a curse its waters have become a blessing; whilst the mistral, the northwest wind, the great drawback to life in Marseilles, and in all Provence, that at times sweeps with terrible force over the country up-rooting trees and destroying buildings, has, owing to the greatly increased humidity of the atmosphere, caused by the irrigations from the Durance, lost much of its former force, is less frequent, and of shorter duration. It is supposed that the mountains here were once covered with timber, the rain-fall regular, and the land fertile; but their denudation of timber deprived the country of a storage for humidity; the rain-fall becoming irregular caused the volume of water in the streams to vary greatly, mountain detritus was spread over the formerly fertile plains; the heat and duration of summer became greatly augmented, and the hot air arising from the parched arid earth originated the mistral.

There are five groups of mountains and they take up three-quarters of the department. The topography in this section is the most varied, the mass being twisted into peaks and chains, between which lie valleys, lakes, and ponds. The plains la Crau and la Camarque take up the remaining superficies of the department. They incline slightly towards the sea and the large rivers. La Crau, comprising 35,000 hectares, of which 15,000 are cultivated and irrigated (1875), is formed mainly of pebbles brought down from the Alps in the glacial period. Before the construction of the canal de Craponne la Crau was one vast uncultivated tract, affording but a scant and coarse pasturage enjoyed in common by the inhabitants. Since the coming of the canal this region has been metamorphosed; rich farms spread over what was once but a desert. La Camarque is that vast delta comprised between the two great branches that the Rhône divides itself into before entering the sea.

It keeps growing constantly from the additions made to it by the deposit of matter carried down by the river in suspension. In area it is 88,300 hectares; 50,000 are wild, uncultivated pasturage, and 23,000 marshes and ponds, and 15,300 under cultivation. There are several canals in this section, but the figures above show how much remains to be done. The history of the formation of this plain by the river dates back to 400 B. C. From statistics of 1855 it appears that of the whole area of the department about 7 per cent. is water.

	Hectares.
Ponds and irrigating canals	456.75
Transportation canals	44.38
Lagoons	11,565.34
Rivers, lakes, streams	23,270.64
Total water area	35,337.11

Considerable tracts of land formerly under water have been reclaimed. In some cases a canal for drawing off the water from swamps and marshes has also been used for irrigation. These reclaimed lands when properly drained and watered have proved fertile enough to pay handsomely those who had the foresight to plan and execute the necessary work.

When we come to examine into the quantity and quality of crops grown and the increase in and of the same due to irrigation, we are met with the difficulty of statistics that are conflicting and at times irreconcilable.

Even in the extent of the department we find—

Area of department statistics of—	Hectares.
1864	512,232
1867	496,464
1870	510,487

a difference for which no explanation is given.

A table of agricultural statistics was prepared by M. Villeneuve in 1820 and one by the Government in 1870, which are taken as reliable. It will be seen that both these tables make the departmental area about the same. In 1820 the cultivated land was 169,000 hectares to 341,000 hectares uncultivated, or as 1 is to 2; while in 1870, if we add the woods to the uncultivated, we have: Cultivated, 201,000 hectares; uncultivated, 309,000, or as 2 is to 3, instead of as 1 is to 2, in 1820; a gain of 32,000 hectares of cultivated land in fifty years, or about 19 per cent. Here are the tables:

1820.

	Hectares.	
Cultivated:		
Arable land	105,000	
Meadows	16,000	
Vineyards	20,000	
Olives	24,000	
Gardens and pleasure ground	4,000	
		169,000
Uncultivated:		
Waste land	233,000	
Lagoons and swamps	47,000	
Woods, bush, and scrub	61,000	
		341,000
Total area		510,000

1870.

	Hectares.	
Wheat	70,200	
Rye	390	
Barley	1,000	
Oats	8,400	
Corn	50	
Seeds and dry vegetables	6,650	
Potatoes	5,900	
Cabbages, carots, beets, etc	6,000	
Madder	1,490	
Tobacco	80	
Hemp and teasels	980	
Fallow land	20,000	
Arable land		121,140

	Hectares.	
Olives	12,000	
Vineyards	29,300	
Mulberries	3,000	
Almonds and other fruit	13,000	
Orchards	1,300	
Gardens and pleasure	4,000	
Tree cultivation		62,600
Meadows, dry	3,400	
Meadows, irrigated	5,900	
Clover and other fields	8,200	
Grazing and fodder		17,500
Woods and forests	87,800	
Willows and wickers	3,200	
		91,000
Heath and wild pasture	104,860	
Taxable built property	1,800	
Lagoons	35,000	
Marshes	17,000	
Roads, water courses, and uncultivated lands	59,587	
		218,247
Total area		510,487

According to the Government report of 1875 it appears that this increase of 32,000 hectares of cultivated land in fifty years was due solely to irrigation, there being about that much more land irrigated in 1870 than there was in 1820.

Statistics in France are not obtainable for periods of more than fifteen or twenty years at a time, then a break of a year or two occurs caused by a revolution and a change in the form of government, so that we have no statistics covering very long periods, we have them only in sections.

Taking up the agricultural products somewhat in detail and making a comparison of certain years as obtained from statistics, we have for cereals in 1840, 70,312 hectares devoted to their culture, and after a period of thirty-two years, 1872, 82,223 hectares employed in the same culture.

Wheat shows an increase of over 30 per cent.; oats remain about the same; rye, which in 1840 was 2,711, in 1872 falls to 380; barley, in 1840, 4,211, to 2,507 in 1872; corn, in 1840, 56, to 30 in 1872, the tables showing an increase in area sown in cereals of 16½ per cent. in thirty-two years.

1840.

	Hectares.		Hectares.
Wheat	53,232	Madder	4,143
Maslin (wheat and rye)	1,135	Teasels	1,112
Rye	2,711	Hemp	31
Barley	4,211	Mulberries	1,456
Oats	8,967	Natural meadows	5,475
Corn and millet	56	Clover and other fields	5,470
		Fallow land	64,432
Total cereals	70,312	Woods (commons and private)	103,421
Vineyards	24,991	Orchards and plantations	6,126
Potatoes	2,415		
Dry vegetables (beans, etc.)	2,207	Total agricultural area	463,697
Gardens	2,042	Roads, water-courses, etc	49,294
Beet-root	307		
Olives	24,475	Total area	512,991

	1871.	1872.
	Hectares.	*Hectares.*
Wheat	70,858	71,119
Rye	290	380
Barley	350	2,507
(Maize) corn	40	30
Oats	7,346	8,187
Total cereals	.....	82,223
Dried vegetables (beans, peas, etc.)	5,509	3,650
Potatoes	6,569	5,709
Tobacco	100	217
Beet	129	400
Madder	1,490	1,400
Hemp	3	3
Olive orchards	12,000	12,000
Vineyards	29,397	28,897
Fallow land	*23,000	.....
Natural meadows	*9,000	.....
Clover and other fields (sown)	*10,000	.....
Woods and forests †	*58,000	.....
Wild pasturage	*140,000	.....
Other lands	*138,206	.....
Total area	510,487	.....

* Approximated.

† Woods and forests belong to the department, to public establishments, to commerce, and to individual owners.

The increased area devoted to wheat was obtained from cultivating waste land. From 1820 to 1839, 65,000 hectares were anually sown in cereals; from 1840 to 1859, a mean annual of 76,000; from 1860 to 1874, a mean annual acreage of over 78,000.

As to the yield of wheat per hectare, it varies not only on different farms, but on the same farm in different years. A good year returns about 15 hectoliters to the hectare, or about $16\frac{2}{5}$ bushels to the acre. In 1868 the yield per hectare was only 8.05 hectoliters, or about 9 bushels to the acre. The wheat, winter wheat almost exclusively, is sown two consecutive years on the same land, which is then given a year's rest.

Of fallow land—arable land permitted to lie idle—there was in the department in 1840 60,000 hectares; in 1852 this had fallen to 29,000, and since 1862 to less than 23,000.

The jury who examined the irrigated farms in 1875 and awarded the prizes* state in the "rapport" that the disappearance of idle land is due to irrigation.

* The prizes referred to were offered by the French Government in 1875 to encourage the advancement of agriculture by irrigation. First prize, farms of over 4 hectares showing best results from irrigation, a gold medal and 1,000 francs; second, 700 francs; third, 600 francs.

For farms of less than 4 hectares: First prize, gold medal and 600 francs; second, 500 francs; third, 300 francs. A silver medal accompanied the second prizes and a bronze one the third. It was intended that the "concours" should last for five years, but it seems that it was given up after two years. The first year thirty-nine farmers contended for the prizes, and the jury who visited their farms made a brief report on each one; their report is to be found in the "rapport" for 1875 that accompanies this brief investigation.

The statistics for the cereals, 1860 to 1874, fifteen years referred to above, are:

Year.	Areas sown with—					
	Wheat.	Rye.	Barley.	Maize.	Oats.	Total of cereals.
	Hectares.	*Hectares.*	*Hectares.*	*Hectares.*	*Hectares.*	*Hectares.*
1860	78,900	1,294	1,937	.....	9,000	91,131
1861	63,054	515	1,044	.....	8,066	72,679
1862	61,652	649	1,039	.....	7,557	70,897
1863	62,539	646	2,072	.....	7,891	73,148
1864	67,040	665	1,075	.....	6,717	75,497
1865	63,875	462	1,200	.....	8,086	74,423
1866	67,418	648	2,133	.....	8,042	78,241
1867	70,100	350	500	.....	8,500	79,450
1868	68,200	300	500	.....	8,100	77,100
1869	70,000	300	492	.....	8,100	78,892
1870*	.....	.....	.....	.....	.....	.....
1871	70,858	290	550	40	7,346	79,084
1872	71,119	380	2,507	30	8,187	82,523
1873	69,975	450	595	65	11,431	82,516
1874	68,775	430	598	70	6,562	76,365
Average of fifteen years	68,107	527	1,160	51	8,170	78,015

* No statistics by reason of the war.

[Quantities in hectoliters.]

Year.	Wheat.		Rye.		Barley.		Oats.	
	Aggregrte.	Per hectare.	Aggregate.	Per hectare.	Aggregate.	Per hectare.	Aggregate.	Per hectare.
1860	1,218,358	15.43	11,888	9.20	41,916	21.65	180,000	20.00
1861	731,426	11.60	5,834	11.33	5,971	5.72	141,558	17.55
1862	600,490	9.74	7,353	11.33	16,886	16.25	115,547	15.28
1863	750,458	11.45	5,943	8.93	38,539	18.60	133,674	16.94
1864	905,040	13.50	8,795	13.22	19,511	18.15	134,407	20.04
1865	818,878	12.82	6,929	15.00	21,648	16.03	176,920	19.91
1866	968,122	14.36	9,849	15.20	30,812	14.44	141,459	17.59
1867	829,984	11.84	5,320	15.20	7,310	14.62	159,800	18.80
1868	551,056	8.05	3,990	13.30	5,950	11.90	110,573	13.65
1869	933,100	13.33	4,500	15.00	10,627	21.60	110,573	13.65
1870*	.....	.....	.....	.....	.....	.....	.....	.....
1871	1,159,945	15.54	3,520	12.14	11,880	21.60	189,522	25.80
1872	1,101,795	15.50	4,856	12.78	44,488	17.74	195,424	23.87
1873	984,548	14.07	5,301	11.78	6,878	11.55	317,095	27.74
1874	1,152,732	16.75	6,536	15.20	8,999	15.05	196,909	30.00
Average crop per hectare	.....	13.14	.....	12.61	.....	16.20	.....	20.06

* No statistics by reason of the war.

The other more important products of the department are: Potatoes; vegetables, dried and fresh; the olive, vine, fruits, and tobacco. In their cultivation arrosage from the canals is being used more and more every year, as will appear later on.

For potatoes we have:

	Hectares.
1840	2,415
1852	3,446
1871	6,569
1872	5,729

No statistics as to yield per hectare.

For dried vegetables, beans, peas, lentils:

	Hectares.
1840	2,207
1852	2,608
1862	3,407
1871	3,509
1872	3,650

Fresh vegetables, market gardening, in 1862, 4,117 hectares. Since that time the raising of "primeurs" for the London, Paris, and Marseilles markets has greatly increased, so that the acreage now given to fresh vegetables exceeds 6,000 hectares.

The olive fell off from 24,000 hectares in 1840 to half that figure in 1872. This was caused by the large importation of Italian olive-oil and also to serious losses sustained by the French olive farmers, due to a succession of heavy frosts.

The vine has experienced many vicissitudes and shows great fluctuation.

	Hectares.
1840	24,991
1855	44,069
1869	61,303
1872	28,897

The old method of sowing wheat, etc., in the spaces, 1 to 2 meters between the rows of vines, is now regarded as very bad farming, neither harvest being up to the full yield, and the land is rapidly impoverished by the double work exacted of it. In 1866 a new enemy of the vine made its appearance in Vaucluse, and from thence gradually spread over the greater part of France, threatening the total destruction of viniculture. This was the phylloxera, a microscopically small bug, prodigiously fecund, multiplying itself by myriads on the roots of the affected vines, and exhausting the sap until the plant died. This insect after destroying one vineyard migrates to the next to continue its work. Various expedients were tried to kill the enemy, the object being to find some substance that, mixed with the earth, would destroy the insect without injury to the vine; but these efforts were not crowned with complete success.

A viticulteur, M. Francon, of the Bouches du Rhône, conceived the idea of drowning the pest, and it now appears that if the afflicted vines are submerged under water for a sufficiently long time they are completely freed from it. M. Francon submerged his vines for thirty consecutive days immediately after the vintage and killed the phylloxera without injuring the vine. The quantity of water necessary to submerge a vineyard depends on the permeability of the soil. About 864 cubic meters of water every twenty-four hours for each hectare was sufficient in M. Francon's case. The earth must be completely saturated to the depth of the roots. The submersion being accomplished the vines should be pruned and manured. This, of course, in the autumn after the vintage.

Among fruits the almond has been increasing in favor steadily since 1860. From 1,500 hectares in 1860 the number went up to 7,000 in 1870.

Other plantations of less extent and importance are: Figs, capers, jujube, pistache, peach, apple, pears, cherries, apricots, pomegranates, medlars, quinces, walnut, prunes, and agerole.

Much greater care and study is required for irrigating with good results the larger fruit trees than is necessary with the cereals and vegetables.

In 1863 there were seven hundred and fifty-two farmers, who raised 183,500 kilos of tobacco on 124 hectares, which the Government report of 1875 says paid them 945 francs per hectare, or about $90 per acre. In 1875 there were only two hundred and sixty-five farmers raising tobacco on 43 hectares. These are the last statistics. Now as to cost of production. Heavy manuring and frequent arrosage are required. The decline in tobacco production is partly explained by Government interference. A special permit must be obtained to raise it, and the Government specifies the kind of tobacco to be grown. It can be sold only to certain firms and at a fixed price. Its production in this department is unimportant.

One is led to compare southern California with Provence. The first has a milder average climate and a richer soil, enabling it to produce even a greater variety of fruit, in addition to the cereals, than southern France. It is stated that the counties of Los Angeles, Santa Barbara, Ventura, San Bernardino, and San Diego are alone capable of producing all the figs, grapes, olives, oranges, lemons, nuts, and prunes imported from France, Spain, and Italy. When land there is improved with bearing vines and fruit trees it brings from $100 to $500 per acre, while unimproved land can be had for one-fifth that price. Unimproved land in southern France means non-irrigable land, and can be had for $15 per acre, while lands of identically the same soil that are irrigated (*qui sont arrosés*), bring $500 per acre, devoted to the olive, small fruits, etc. These are the land values given by M. Menestrel in 1822, and it seems they are about the same to-day.

Southern California presents a similar climate, better soil, doing away with or greatly lessening the use of manure, one of the heaviest items in French farming, and needing but one thing—irrigation—to make the whole country as productive as the very choicest sections now are and capable of supporting an immense population. The most important question for southern California is irrigation, a rural economy that has been studied and successfuly practiced here for centuries.

While the cereals seem to be suited to large farming (*la grande culture*,) the vine, olive, small fruits, etc., pay better when produced on a small scale (*la petite culture*).

Southern California should be divided up into thousands of small fruit farms. French properties of this sort are frequently not more than 20 acres, sometimes much less, that being all the land one average family can cultivate without the employment of hired labor. The products of such a farm are raised on small patches.

One frequently sees but one acre given to wheat, another to the vine or olive, several for gardening, and the remainder in pasture on a 10 or 15 acre farm. The diversity of production prevents the farm work from being over-exacting at any one period, enabling the family to work on the different crops at different times, and keeping it busy all the year round. Besides it is found, even on these small farms, marked differences in the soil occur, so that experience has taught that it is more profitable to divide up 10 acres in several cultures than to confine them to but one. These small farms require little or no machinery in the American sense of the word.

Southern California should be covered with a net-work of irrigating canals as is the Bouches du Rhône. It appears that the Santa Anna is tapped to such an extent that in summer the river bed is perfectly dry and the irrigating value of its waters quite limited. By the construction of reservoirs for the storage of the waters that are allowed to escape to the sea in winter the irrigable area can be increased to any desired extent.

It is interesting to note that just as the water supply for arrosage in the Midi was and is managed by companies, so we read in the San Bernardino Times that "the Ontario Land Company has driven a tunnel in under San Antonio Creek a distance of nearly 1,800 feet at a cost of about $52,000, and they have about 250 inches of water, worth $250,000.

Part II. Irrigating canals, their origin and management, will be forwarded as soon as certain statistics can bo obtained.

REPORT FROM F. F. DUFAIR, U. S. CONSUL, HAVRE.

[WITH INCLOSURES ON IRRIGATION IN THE DEPARTMENTS OF MANCHE, ILLE-ET-VILAINE, AND MAYENNE.]

This service (irrigation) is under the immediate management of the chief engineer of ponts et e chaussés (roads and bridges) in each department of France and under the head control of the chief engineer, director of agricultural hydraulics, Mr. Philippe, of the ministry of agriculture, at Paris.

The fact that Mr. Quinette de Rochemont, the head engineer of the port of Havre, has been absent for some weeks, the only government officer who could give me the desired information, must plead my excuse for not reporting before this.

From him I learned that there is no system of irrigation in the arrondissements of Havre and Yvetot, in the department of the Seine-Inférieure; the remainder of this department is under the management of Mr. Vivenot, chief engineer at Rouen. The chief engineers of the departments in my consular district, besides the above named, are Mr. Lucau, at Caen, Calvados; Mr. Perrin, at Alençon, Orne; A. Gouton, Cherbourg, Manche; L. Rousseau, Rennes, Ille-et-Vilaine; Floueand de Fourzeroy, Laval, Mayenne, to whom I addressed myself for the required information, and, with the exception of the two first named, they very obligingly answered my questions by the letters herewith inclosed, accompanied with my translation.

[Translation.]

LETTER OF A. GOUTON, CHIEF ENGINEER OF ROADS AND BRIDGES OF THE DEPARTMENT LA MANCHE.

CHERBOURG, *August* 17, 1889.

In answer to the request for information which you were pleased to address to me on the 8th of this month, I have the honor to say that there is very little irrigation, properly called, practiced in this department for summer watering. On the contrary, the climate, which is a most temperate one, makes submersions of low meadows during the winter months by means of brackish water very useful.

With these general remarks permit me to sum up the answers to questions 1 to 6 as follows:

(1) I have no data as to the extent of irrigable compared with non-irrigable or cultivated land in the department. It consists of pasture land for grazing cattle, or of meadows furnishing mowed hay.

The quality of this pasturage is most excellent, such as that of Isigny, Bessin (neighborhood of Bayen), Carentan (or, properly called, Cotentin), Valognes, etc., producing the famous butter of Isigny and Cotentin, the best in France.

(2) The water producing this rich grass in the department of Manche is almost exclusively rain-water. Rains are very frequent but rarely stormy or chilling, and

the average annual rain-fall at Cherbourg or Isigny reaches from 1 to 1.10 meter (39⅜ to 42 inches).

There are numerous springs, brooks, and streams, but it is only in the winter time, with rare exceptions, that lands are being overflowed.

(3) Therefore there are no reservoirs, only simple trenches, for the distribution of the water on irrigated meadows.

(4) The usage of water for irrigation is regulated by common law (articles 643, 644, 645, code civil) and the laws of April 29, 1845, and July 11, 1847.

Besides that, work of irrigation occasions syndical associations, subject to the law of June 21, 1865.

(5) The climate of the soil is most variable in the department of Manche, presenting the greatest variety of geological formations next to tillable soil.

(6) The local habit of submerging lands in the winter months in sweet water is very ancient; it is principally practiced on meadows and pastures near the sea, where the soil is below the level of high tides.

Winter irrigation in other regions of the department is in the hands of individuals without either rules or co-operation.

The general service of the water-courses, useful as well as detrimental to agriculture, devolves upon the department of ponts et chaussées (roads and bridges), having charge of agricultural hydraulics and belonging to the minister of agriculture.

[Translation.]

LETTER OF LÉON ROUSSEAU, CHIEF ENGINEER OF THE DEPARTMENT OF ILLE-ET-VILAINE.

RENNES, *August* 14, 1889.

SIR: Irrigation in the Department of Ille-et-Vilaine is of very small importance. Here is in a few words my report to the minister of agriculture:

Regular irrigation, that is to say, such as permits the possibility to admit and to draw off again the waters according to the requirements of cultivation at the proper time, is extremely rare.

One single instance of this kind has been submitted to the engineers in 1888 concerning the brook Français, on the confines of the departments of Ille-et-Vilaine and Manche.

Elsewhere irrigation consists only in submersion, in consequence of the rise of brooks, of natural meadows situated in the bottom of their valleys. The receding of the waters into their beds after freshets is facilitated by a great number of trenches dug at the confines of the several parcels of fields or traced according to the depressions of the soil.

Submersions are also practiced in some dried up ponds which have been transformed into meadows. These ponds having been drained by breaching a dike or highway to allow the water to run off, the system of irrigation consists in temporarily stopping up such breach to allow the water to rise and to overflow the neighboring fields.

LÉON ROUSSEAU,
Chief Engineer of Road and Bridges, Ille-et-Vilaine.

[Translation.]

LETTER OF MR. FLOUAND DE FOUZEROY, CHIEF ENGINEER OF ROAD AND BRIDGES, DEPARTMENT OF MAYENNE.

LAVAL, *August* 10, 1889.

SIR: You are pleased to send me an interrogatory regarding irrigation.

I should have been happy to answer it, as far as this department is concerned, but it would be difficult to do so in a precise manner.

Irrigation is frequent in this department, where the soil is very much broken and divided into a great many basins; there are thus many small and rapid water-courses, where it is easy to construct small dams and to turn the water into trenches to irrigate numerous natural meadows; but there are no statistics existing to state the extent of land susceptible of irrigation compared with such as is non-susceptible.

There are no reservoirs; there is only one syndical association of small importance occupying itself, principally, with the draining of meadows with the view of making them salubrious.

The climate is rather rainy, the subsoil impervious; there are no extended or deep valleys, neither are there table-lands or heaths.

On the whole I don't believe that the interrogatory which you did me the honor of addressing to me can be answered in an interesting or precise manner.

Please accept, etc.

FLOUAND DE FOUZEROY.

REPORT FROM ALBERT N. HATHAWAY, U. S. CONSUL, NICE, ON IRRIGATION IN SOUTHERN FRANCE.

Irrigation here is applied for the most part to ornamental, horticultural, and vegetable gardens, instead of to fields of general agriculture, and to no grain lands whatever, and in but small extent to the vineyards and orchards of oranges, lemon, and olive. The expense for flowage water, procured from the hydrants works of the city of Nice, renders such use largely unprofitable, and the scarcity of the natural supply precludes its systematic application to any wide degree, except in the valleys of the Var and lesser rivers. When irrigation here is practiced production is doubled without injury to the quality of the crop; sterile soils, long useless, recover and yield abundantly, and in many localities, to insure valuable returns to the husbandman, it is of absolute necessity.

The ordinary sources of water, for the purpose, are ancient wells from which, during hours in each day, it is drawn by mule-power and quite primitive machinery into distributing tanks and inherited slow methods of labor.

The said company having obtained a concession, with an appropriation therewith of two and one-half millions from the state, was organized in 1878 and its works established at a cost of 12,000,000 francs.

Its supply is obtained from the river Vesubie, in the valley of that name, distant about 30 miles from Nice, from which river it is led, flowing at the rate of 4,000 liters each second, in an open, cemented canal to a distributing reservoir on the heights in the suburbs of said city. In its treaty with Nice the company is bound to supply the city, for the annual payment of 80,000 francs, with 60,000 cubic meters of water daily for its abattoirs, sewers, fountains, and public works. The water for domestic uses, also provided by said company, is derived from a separate source, viz, the mountain springs of Sainte Thecle. Under the aforesaid concession from the state the company covenants, during the term thereof, viz, until 1972, to maintain the construction of their works for the public utility of the region and to furnish flowage at fixed prices therein stipulated. Otherwise than this, said corporation is unsubjected generally to the Government control. The established tariff for its continued use for irrigation on ordinary levels is as follows, viz: For 1 cubic liter per day, annually, 30 francs; for 2 cubic liters per day, annually, 55 francs; for 3 cubic liters per day, annually, 60 francs, and for each additional daily cubic liter, 20 francs annually. The tariff for its periodical use is proportionate to the above table, conditioned, however, to an agreement as to quantity to be consumed. The service pipes are in all cases at the charge of the proprietor.

The region, having thus facilities of irrigation, is by nature restricted to the foot-hills and narrow valleys of this district, beyond and above which are the mountains barren of or discouraging to cultivation. The limits, owing to the configuration of the coast, the counter scarps of Alps, and the proximity of the sea, which serves as a vast reflector of

the sunbeams, is semi-tropical in character. The soil, producing two or more variable crops a year, is alluvial, with a humus surface and a gravelly substratum, and quickly absorbs all moisture. In May the temperature averages 64°, in June 70°, and in July and August 78° Fah. In winter it averages 52°. From May to November more than one hundred days are usually without clouds. The average rain-fall is from 80 to 100 centimeters per annum.

REPORT FROM EDWARD CAMPHAUSEN, U. S. CONSUL, NAPLES, ON IRRIGATION IN SOUTHERN ITALY.

I have the honor to report that on receipt of your circular instructing me to furnish information on the subject of irrigation as practiced in this country, I immediately applied for statistics to the prefect of the ten provinces composing this consular district.

In course of time, after the delay usual to these officials, they replied that, owing to the scarcity of water-courses, there were no lands under irrigation in their respective provinces. It is claimed that the geological and lithological condition of the country are such that it would be impossible to carry any system of irrigation into effect.

This country depends absolutely on the rain falling mainly during the months from November to April. The average annual rain-fall is said to be about 20 inches. There are some lands under private irrigation. The water supply belonging to the respective land-owners is taken from wells, at a depth varying from 25 to 100 feet, water being found in abundance at that depth in most parts of the country. Near the coast of the Adriatic and Mediterranean wells are formed by the infiltration of salt water. Some of these belong to communities, but no definite law or regulations appear to exist for the use or distribution of the water, and there is no irrigated land, in the true sense of the word, in this district.

I inclose a copy of the law concerning the derivation of public waters and also a publication discussing a project for supplying the province of Ban with water for domestic purposes.

REPORT FROM EDWARD P. EARLE, U. S. CONSUL, COGNAC, ON IRRIGATION IN THE DEPARTMENT OF LA CHARENTE.

I deferred answering the Department's circular of May 2, 1889, concerning the methods of irrigation in use in my consular district, until I could fully possess myself of the facts of the case. To this end I sent the circular, through Hon. Oscar Planat, the mayor of Cognac, to the chief engineer of La Charente, at Angoulême. I received from him a few days ago, through the mayor, a long, rambling reply to my interrogatories, which may be summed up as follows:

(1) That the engineer has no knowledge of any system of irrigation now in practical use in this department.

(2) That all his information is derived from the library and archives of his office, and finally that he refers me to the departments forming the old government of Provence. There, he says, extensive systems of irrigation are practiced. He also suggests that inquiries should be addressed to the minister of agriculture, at Paris.

For my own part here are my observations:

This part of France is quite abundantly watered; the Charente, the Nee, and many other smaller streams traverse it, and so far as my ob-

servation extends the question with farmers here is what to do with surplus water rather than any question of irrigation. All the canals, dikes, and ditches are exclusively for the purpose of restraining overflows or for draining wet or submerged lands. The river and creek bottoms are generally broad and level and very subject to overflow, to the great detriment of the grass planted thereon. The receding waters leave a fine deposit of mud on the stems and blades of the grass, which, drying with the hay, becomes a dust very damaging to the stock eating it. At this moment, when the new hay crop is come into market, almost all the horses of the arrondissement are affected with a severe cough like that of hay fever.

The highlands of this arrondissement are quite out of the reach, in my judgment, of any practicable system of irrigation, nor does it require it. Some seasons are said to be very dry, but a protracted drought I take it, is a rather rare occurrence. The principal characteristics of the climate appears to be its humidity. The night moistures or dews seem to me quite sufficient by themselves, the soil meanwhile being a little stirred to furnish all the plant requires.

I send no maps, published reports, or books on the subject of irrigation in France, as the consul at Marseilles, where that system of agriculture prevails, can make a more discriminating selection than I could here. I content myself with saying, in fine, that no system of irrigation prevails in my consular district. I do not know, nor have I been able to find, any competent expert on that subject.

REPORT FROM WALLACE S. JONES, U. S. CONSUL, MESSINA, ON IRRIGATION IN THE PROVINCE OF MESSINA, SICILY.

Irrigation in Sicily dates from the occupation of the island by the Mussulmen. They took possession of Palermo in 831, and gradually extended their sway. Ruins of the Emir's castles, agricultural terms still in use relating particularly to irrigation, and numerous African plants all testify to their former presence here. In the year 872 they first began the use of the "*noria*" (*senie*), raising well water into water towers (*giarraton*) or cisterns (*giabiat*), whence it was distributed by means of small ditches (*sajat*), and this is the system in general use today.

Irrigation did not attain the same development in this province as in that of Palermo for the reason that water veins are not as numerous here. Since 1850 the search for water has been steadily on the increase, due to new methods of reaching it (by drilling) and of raising it (by endless chains of iron buckets instead of the old-fashioned *noria* with paddles) and to improved gearing. Water is pumped up, and many of the wells are 100 feet deep and over, by horse-power; oxen are also much used for this work, and occasionally by steam-power. There is no coal in Sicily, and the lack of roads makes its transportation from the seashore too expensive.

According to the Italian civil code all waste under the beds of rivers or torrents belongs to the State; but while this is the law it happens, nevertheless, that owners of land along the water-courses use the water with more or less immensity, so that but a small quantity may be said actually to belong to the public domain.

The supply of water for irrigating purposes in this province is small. The extremely mountainous district of Val Demone is not adapted to the percolation of rain-water, particularly as a short-sighted policy has

destroyed the natural reservoirs, the forests, thus permitting the rain to run off and waste. As a result not a single river is to be found in the province, but we meet at every hand destructive torrents (their beds are dry in summer), whose havoc is ever on the increase. There are no less than thirty torrents in a stretch of country 45 miles wide in this province. Natural springs are but few, so that the greater portion of the water used for irrigation as well as for drinking purposes is obtained by means of costly hydraulic works, tunnels, wells, cisterns.

The topography of the Messina district does not allow of the formation of lakes, and, with the exception of two small brackish sheets of water near the Faro and of a fresh-water pond in the commune of Rouella Valdemone, we find no lakes here.

Owing to the deficiency in the water supply and to the greater portion of this district being mountainous but one-sixteenth of the total cultivable area (*i. e.*, 14,000 hectares) is irrigated. Of the irrigated area:

	Hectares.
Oranges and lemons occupy	7,600
Market gardens*	800
Flax and hemp	200
Indian corn	1,000
Legumes (beans)	1,400
Fruit trees, peaches, pears, etc	500
Reed cane	2,000
Marshes	500
	14,000

Irrigated land produces crops not only superior as to quality but threefold as to quantity compared with non-irrigated land. Irrigated open land sells for three times as much as the non-irrigated; near the city of Messina it fetches from $780 to $1,230 per acre.

The water is pumped into well-cemented reservoirs or vats, generally prismatic in form (because cheaper), rarely circular. We also meet with covered cisterns. From the collecting reservoir the water is made to pass into the distributing reservoir through gutters called "condotti," or "tubi," conduits or pipes. The water is carried from the distributing reservoir to different parts of the grove, either by trenches called "sajat," or by brick conduits either closed or open on top. The latter are known as "brinzi."

The open conduits are to be preferred, because they do not choke and because they are not liable to burst.

Should the grove be extensive, small distributing reservoirs called "bisternoli" are established here and there.

This distributing of water for irrigation purposes, when the water is private property (for by law the owner is allowed to make what use of it he pleases, provided he does no damage to his neighbors), is not governed by law, but by special customs that vary with the locality and which it would be impossible to enumerate.

The cost of water for irrigation purposes is so complicated a matter that it can not be fixed precisely, but this much can be said: In this province a penna (a goose-quill) of water, *i. e.*, 36 gallons of water per hour, costs from $200 to $260 per annum.

Here, as a rule, water is private property. Some communes own water either by purchase from private parties or because its source is on community land.

The title to water is acquired by bargain and sale, exchange, gift,

*It should be added that garden truck is very generally cultivated in the vacant spaces in orange and lemon groves.

and can also be acquired by prescription. Not less than thirty years of undisturbed enjoyment are necessary to create title by prescription.

As to the climate of this province, the maximum of heat is 87° Fah. Some winters the thermometer falls to 20° below freezing, but this temperature prevails for a very short period. Snow covers the tops of the mountains for several months during the winter, and nearly every year reaches the sea-shore, covering the ground for a few hours. At Messina the temperature changes with the currents (which are tidal) that pass through the straits. From October to December it rains frequently; in January and February it rains and snows; in March and April it rains constantly. Open weather begins in May and lasts to September with an occasional heavy down-pour. Annual rain-fall 22 inches. During the spring and autumn months fogs prevail on the mountains; it rarely hails; dew and white frost occur frequently; frost in April inflicts considerable damage.

No hydrographic maps or publications bearing upon irrigation in this province exist. Less attention has been paid to irrigation in Sicily than in any other portion of Italy; but little progress has been made since the days of the Arabs.

A few years ago a technical school for instruction in hydraulics was opened in Palermo. If the water of the numerous torrents in Sicily were to be controlled and utilized in irrigation, many localities now infested by pernicious and malarial fever would become healthy and habitable. Statistics show that one-fifth of this island is subject to the influence of stagnant water and of the dry beds of torrents during the summer and the organic matter accumulated for centuries in these low spots breeds foul emanations that poison the air.

No works for the storage and distribution of water have as yet been undertaken by the Government in Sicily. In 1858 a company with a capital of $150,000 undertook, under a charter from the Bourbon Government, to utilize the water of the River Simeto in irrigating a portion of the plain of Catania, the total area of which is 65,506 acres. A rough stone dam was thrown across the river at Paterno and two principal canals, one to the right (20,000 yards long) and the other to the left (30,000 yards long) of the river-bed were opened down to the ocean. Four secondary canals (leading from the principal canals) were also opened, and these were intersected by numerous irrigation ditches, the latter of a total length of 10,000 yards. The banks of the canals are faced with stone or with logs whenever the land has a tendency to slide. At the dam the canals are 6 feet wide at bottom, 29 feet wide at top, and 6 feet deep; the banks have an incline of 45 degrees.

The dimensions of the canals decrease as you go from the dam. The depth of water in main canals should never exceed 4½ feet. The average mean amount of water that passes through the canals is 722 gallons per second. The company charges $67 per 7 gallons a second from April to October 1, and $33.50 from October 1 to April 1.

In the plain of Catania, on a calcareo, argillaceous soil, wheat legumes and flax require 4¾ inches of water from October to April. Summer pasture lands require 12 inches of water. The very stiff clay lands in this plain appear to be adapted to rice culture only. Quite an area is so flat that the water ponds on the land and the slime left by the water impoverishes the land and makes it more difficult to cultivate. This undertaking has been a failure financially; not only has the original capital been sunk but a debt of $120,000 hangs over the company.

The only other work of importance in Sicily connected with irrigation is the dam 2½ miles above Ferranova, province of Caltanisetta.

This massive stone dam is 360 feet long, 24 feet wide at the base, 15 feet wide at the top, and 30 feet high, and was thrown across the River Gela at a cost of $85,000 by the wealthy Duke of Montelevore, descendant and heir of the great Cortes, as far back as the year 1788. An irrigation canal leads out from either wing of the dam; area irrigated 11,860 acres. Below the dam the water falls on a stone platform 138 feet wide by 123 long, and then follows its old bed to the sea. At the point where this dam is erected the river runs through a gorge, the sides of which constitute natural stone walls. An elliptical gap, 80 feet wide by 10 feet deep, has been left towards the middle of the dam. At this point fascines are thrown against the dam on the water side, and earth is thrown on the facines, constituting as it were a floating island, the surface of which is brought almost to a level with the dam on either side of it. Pistachio trees, tamarack shrubs, and grass are set to grow on this island, which serves as a tumbling dam.

As the water rises it gradually rus off, overflowing the island, which, in times of a strong freshet, is carried away bodily. It costs $500 per annum to keep up this island; it would cost $800 to replace it. The land irrigated by means of this dam produced from 1862 to 1865, 5,000 bales of cotton (of 450 pounds) per annum. Cotton is still grown for home wants on a small scale.

Since 1865, the Italian Government has expended large sums in draining marshes, lakes, and ponds, and in controlling the course of rivers and torrents in Northern and Central Italy. Valuable documents, not for sale, however, treating of these works have been published by the minister of public works. As yet no government report has been published treating of works of irrigation, and to get at figures it would be necessary to apply to the several prefectures of the several provinces.

By the law of December 25, 1883, the Government is empowered to loan funds (principal payable in thirty years) at 30 per cent. to irrigation associations (consozzi) and to provinces and communes for the purpose of carrying on works of irrigation, provided the supply of water to be obtained shall be not less than 25 gallons per second and provided the province or commune advances an amount at least equal to one-tenth of the sum loaned by the state.

REPORT FROM CONSUL JONES ON IRRIGATION OF ORANGE AND LEMON GROVES IN SICILY.

In Sicily, generally speaking, no attempt is made to grow oranges or lemons unless it be possible to water the trees during the summer months. There are, however, favored spots (for instance near Aci Reale, 40 miles south of Messina) where, owing to water veins in the subsoil, the trees retain their vigor during the summer. The proportion of non-irrigated to irrigated groves is as 1 to 15 (in extent).

One hundred ten-year old lemon-trees that are watered produce on an average 15,000 lemons, whereas one hundred trees that receive no water (other conditions being equal) produce but 10,000 or one-third less.

The groves are watered from twelve to twenty-five times during the summer, *i. e.*, either once every two weeks or once a week, and at each watering at least 350 cubic meters should be allowed to the hectare (1 hectare=2.47 acres).

At the last spring working of the trees the land is trenched in order to obtain an equal distribution of the water.

Parallel trenches are opened (generally about 6 inches deep and 8 inches wide at the bottom) between the rows of trees, the intermediate space being divided into symmetrical squares or divisions.

If the grove be very level the water is carried from the distributing reservoir by lines of brick pipes (brinze) open on top, resting on narrow stone walls built with the necessary incline to reach the most distant point from the reservoir.

The system is applied to the irrigation of groves where the water supply is abundant and is derived from a stream or spring. Oftentimes when the water must be pumped up by horse-power the tenant, unless it be otherwise stipulated in the contract, will so arrange his trenches as to collect the water in a basin at the foot of the trees. This method is not to be commended, for it retards the developement of the fruit, of the lemons more especially, and predisposes to gum or foot-rot.

One-year-old orange and lemon trees should be watered once a week; three-year-old require water once every twelve days; from the fourth to eighth year, once every two weeks. With the bergamot, however, weekly irrigation is required during the life of the tree. It is always preferable to irrigate during night-time. Isolated trees are sometimes watered by sinking an earthen pipe (3 feet long by 4 inches in diameter) not far from the trees, and filling the same with water. This method has the advantage of causing the tree to send its roots down. The beds of the torrents suck down the water from the springs on the hill-sides. To bring this water to the surface, oblique ditches are cut across the torrent-beds down to the water veins, and a drain (provided with numerous loopholes) in masonry is put in to collect the water. These drains, following more or less the trend of the land, carry the water into the groves to the right and left.

Bastard fruit, *i. e.*, fruit maturing out of season, always commands good prices; hence it frequently happens that tenants allow the trees to go without water during June and July (the trees sicken badly; the leaves turn yellow, and there is great loss of vitality), and begin watering heavily and frequently in August, to form the trees to put on blooms in September, and in that way produce late fruit.

REPORT FROM PHILLIP CARROLL, U. S. CONSUL, PALERMO, SICILY.

(1) There are 508,601 hectares of land embraced in the Province of Palermo, of which one-fortieth is cultivable and irrigable. Nearly 176,000 hectares are under irrigation, yielding on the average an eighth per cent. crop.

(2) Water is derived principally from deep wells, pumps, and reservoirs, the latter being supplied by means of earthen and iron tubes or pipes communicating with the adjacent mountains, as well as by rivers, streams, springs, and falls in a very limited degree, during certain months of the year. The supply of spring water is, however, said to be decreasing.

(3) A pamphlet upon the system of irrigation in the Province of Palermo, by Prof. Ferdinando Alfonso, kindly furnished by the prefect of this province, is inclosed herewith, as to the character of the works used in irrigation.

(4) The distribution of water is governed by its owners, viz, the municipality, the Government, and private individuals, and is based

upon the measures adopted by the municipality of Palermo centuries ago.

The amount of water used on the average is from 300 to 350 cubic meters per hectare of land.

By the system in vogue nearly 17 liters of water can be conveyed to a designated point per second, and an area containing nearly 13 acres can be irrigated weekly, the charge therefor being 5 lire per hour.

Irrigation is commenced on April 15 annually. For obvious reasons it is not resorted to during winter, excepting in prairie lands for promoting the development of grass.

(5) The average annual temperature of the Province of Palermo is 17° centigrade.

In the mountainous regions the climate is temperate, and on the seacoast very warm.

A characteristic of the province is the almost absolute absence of rain from May to September.

The average annual rain-fall of the province is 59 centimeters. Rain later than May is rare and generally meager, and should the usual copious spring rains fail to make their appearance crops suffer severely.

(6) As stated, the present system, consisting of pumps, wells, falls, reservoirs, etc., has obtained for centuries, under the auspices of the municipality of Palermo monasteries and private persons, but since 1866 the Government has controlled the water belonging to religious bodies, it having in that year confiscated all property belonging thereto. The Government either sells or rents this water. The expense is defrayed by the respective owners.

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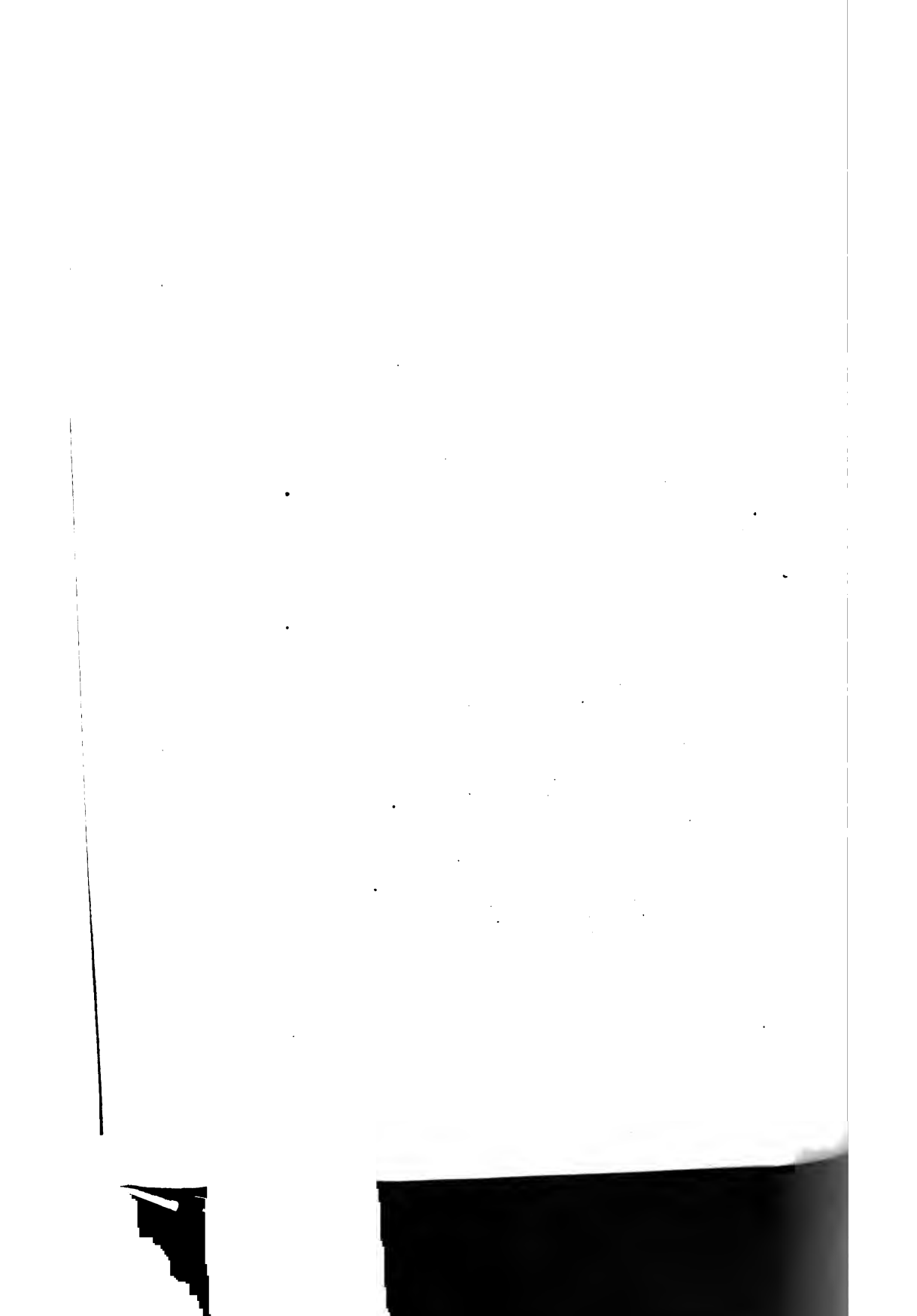

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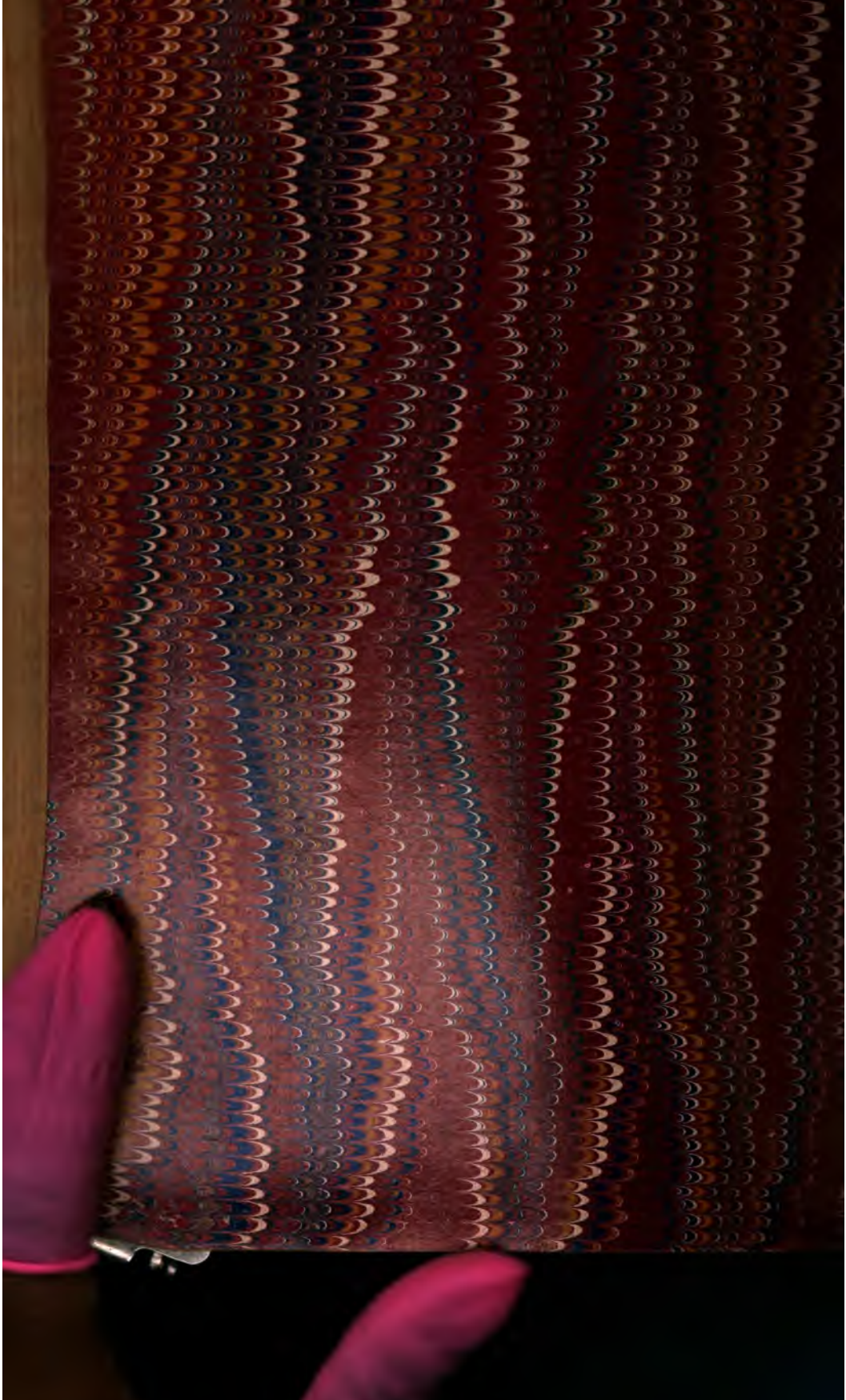
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